Environmental Studies No. 25

The Physical Oceanography of Western Baffin Bay and Lancaster Sound

Northern Affairs Program

D.B. Fissel, D.D. Lemon and J.R. Birch
Arctic Sciences Ltd.
(Revised August 1981)

Published under authority of the Honourable John C. Munro, P.C., M.P., Minister of Indian and Northern Affairs
Ottawa, 1981.
QS-8293-000-EE-A1

Catalogue No. R71-19/25-1981E
ISBN 0-662-11836-7

This report was prepared under contract for Petro-Canada as part of the Eastern Arctic Marine Environmental Studies (EAMES) program. The views, conclusions and recommendations expressed herein are those of the authors and not necessarily those of Petro-Canada or the Department.

A Canadian contribution to the Unesco Program on Man and the Biosphere (MAB).

Cette publication peut être aussi obtenue en français.

EXECUTIVE SUMMARY

Introduction

In 1978 and 1979 ARCTIC SCIENCES LTD. carried out a program of physical oceanographic measurements in Lancaster Sound and Baffin Bay on behalf of Petro-Canada. This project was part of the Eastern Arctic Marine Environmental Studies (EAMES) program, a cooperative industry-government undertaking which covered a wide range of biological, oceanographic, meteorological and ice studies. This report concerns the physical oceanographic segment of the program.

The physical oceanographic studies described in this report were designed to provide information for the assessment of the environmental risks of exploratory drilling in Lancaster Sound and Baffin Bay. The program was intended as an intensive study of the general circulation of Western Baffin Bay and Lancaster Sound. Some site-specific programs were included, but the main purpose of the work was to fill gaps in the existing knowledge of the area circulation.

Physical Oceanographic Field Studies

Following a detailed review of previous physical oceanographic studies in the area, an extensive physical oceanographic field program was designed and carried out during the periods July 1978 to October 1978 and July 1979 to October 1979 from the charter vessel, M.V. Theron. The overall program objective was to provide a data base for a description of the mean circulation and its temporal and spatial variability. The work included the first direct measurements of currents ever made in many parts of the study area.

The field program can be divided into several components, as summarized in Table 1. The data and the methods used in each component are described in considerable detail in separate data reports.

The 1978 studies covered locations from the entrance of Jones Sound in the north to the vicinity of the southern boundary of Baffin Bay, as shown by the CTD and moored current locations plotted in Figure 1. In addition, 15 satellite-track drifting buoys were released to the east of Devon Island and in eastern Lancaster Sound. Current meter moorings which had been deployed in October 1978 were recovered in July 1979 at four sites off the mouth of Lancaster Sound and at a single site off the east coast of Baffin Island. In the summer of 1979, the areal coverage of the program was expanded to include a CTD survey across northern Baffin Bay, CTD stations in Jones Sound, and a drifter and CTD study of western and central Lancaster Sound (see Figure 2). In addition, physical oceanographic studies of nearshore zones were carried out from shore-based camps at Cape Warrender, on Devon Island and Cape Fanshawe, on Bylot Island, along with a ship-based survey off Cape Hay on Bylot Island. On the basis of the 1978 summer results, changes were made in the 1979 summer programs in eastern Lancaster Sound and off Eastern Devon and Bylot Islands, in order to better resolve the intense but relatively narrow circulation features which were found to occur in these areas.

Water Properties

From the cumulative results of previous studies in the area, the horizontal and vertical distribution of water properties (temperature, salinity and density) have been well-defined. The waters of western Baffin Bay and Lancaster Sound can be divided into three vertical layers (Muench, 1971):

(a) The Arctic water, defined by low temperatures (0°C to -1.8°C) and low salinities (31°/oo to about 34°/oo). This generally extends to depths of 200 to 300 m in Baffin Bay and Lancaster Sound.

(b) The Atlantic water, defined by warmer temperatures (0°C to 2°C) and higher salinities (34.2°/oo to 34.5°/oo). This generally extends from the bottom of the Arctic water layer to depths of 600-700 m in Lancaster Sound and 1200-1300 m in northern Baffin Bay.

(c) The Deep water, defined by low temperatures (0°C to 0.4°C) and nearly uniform salinities (34.48°/oo). This layer extends from the bottom of the Atlantic water in Baffin Bay to the seabed.

This basic description of the water layers is generally consistent with the CTD data obtained in the present study.

However, the new data are indicative of changes in detail of the water column structures which are worthy of further description. In particular, Muench's (1971) description requires some modification in its treatment of both the upper 75 metres of the water column, and at the interface of the Arctic Water and Atlantic Water layers. The stratification of the water in these zones is more complex than previously described, and requires further elaboration.

The upper zone of the Arctic Water layer is the portion of the water column extending from the surface to the limit of depths which are directly subject to large spatial and temporal variations due to the effect of surface processes such as solar heating, wind mixing and ice melt. The result of these modification processes is the production of a highly variable surface layer overlying the uniformly cold bulk of the Arctic Water. The range of observed temperatures and salinities is considerably enhanced in the upper layer. From the 1978 and 1979 CTD measurements in the upper zone, the range of observed temperatures was -1.8°C to 3.0°C or greater, while salinities ranging from 20.0°/oo to 32.5°/oo were recorded within the study area.

The depth of the uniform wind-mixed portion of the upper zone is variable, ranging from 0 m in the case of a pycnocline extending to the surface, to as much as 80 m. The mean depth was 13.5 ± 12 m. In offshore areas, where the upper zone is less subject to the advective processes associated with strong coastal currents, the upper zone usually preserves a well-mixed character, and appears to deepen throughout the open water season under wind influence. Although wide variations are observed in surface layer temperature, they have little effect on the density stratification, which is primarily controlled by the salinity distribution. Consequently, away from coastal areas where currents may advect water of different salinity, or fresher water from melting ice, the density stratification in the upper layer is not readily altered once mixing has been achieved.

The transition zone between the cold Arctic water layer and the warmer, more saline Atlantic Water layer is the site of a great deal of interleaving structure in the water temperature. This structure consists of numerous sub-layers of relatively uniform temperature with large vertical temperature gradients occurring at sub-layer boundaries. The thickness of the sub-layers typically ranges from 6 to 30 metres and temperature differences between sub-layers are as large as 0.5°C. The interleaving is present at very reduced amplitude in vertical profiles of salinity and may be a result of the inability of the conductivity circuit of the CTD to respond quickly enough to the rapid vertical changes in temperature. Temperature interleavings were not present at all stations and did not show any discernible spatial pattern beyond a general tendency to follow the distribution of Atlantic Water.

Surface and Near Surface Circulation Patterns

The immediate importance of the Arctic Water layer stems from the fact that it is host to sea ice, icebergs and possible spilled oil. Oil and sea-ice are largely confined to the upper zone of the Arctic water layer while icebergs usually span the upper zone and extend into the Arctic water layer proper.

Table 1. A list of the final data reports for the 1978 and 1979 physical oceanography data and a brief description of the data quantity in each.

Data Report No.	Type of Data	Author	Data Quantity	
			1978	1979
1	Subsurface Currents	D.B. Fissel and G.R. Wilton	Summer: 30 complete and 11 partial time series records Autumn 1978 - Spring 1979: 15 complete and 1 partial time series records.	Summer: 38 complete and 8 partial time series records
2	Satellite-tracked drifters	D.B. Fissel	Tracks of 15 drifters	Tracks of 34 drifters
3	Conductivity, Temperature and Depth (CTD)	D.D. Lemon	193 profiles at 85 stations	328 profiles at 144 stations
4	Current Profiles	D.B. Fissel and J.R. Birch	152 profiles at 50 stations	26 profiles at 26 stations
5	Nearshore Data	J.R. Birch	No nearshore data (N.B. 4 oil spill followers were released from both the Philpots and Bylot drill sites and tracked over a 24 hour period)	Cape Warrender: 33 oil spill follower tracks 16 CTD profiles Cape Fanshawe: 16 oil spill follower tracks 8 TD profiles 1 weather station record Cape Hay: 2 oil spill follower tracks 4 CTD profiles
6	Water Levels	J.R. Birch	One record from August 22, 1978 to May 12, 1979 at Johnson Bay.	

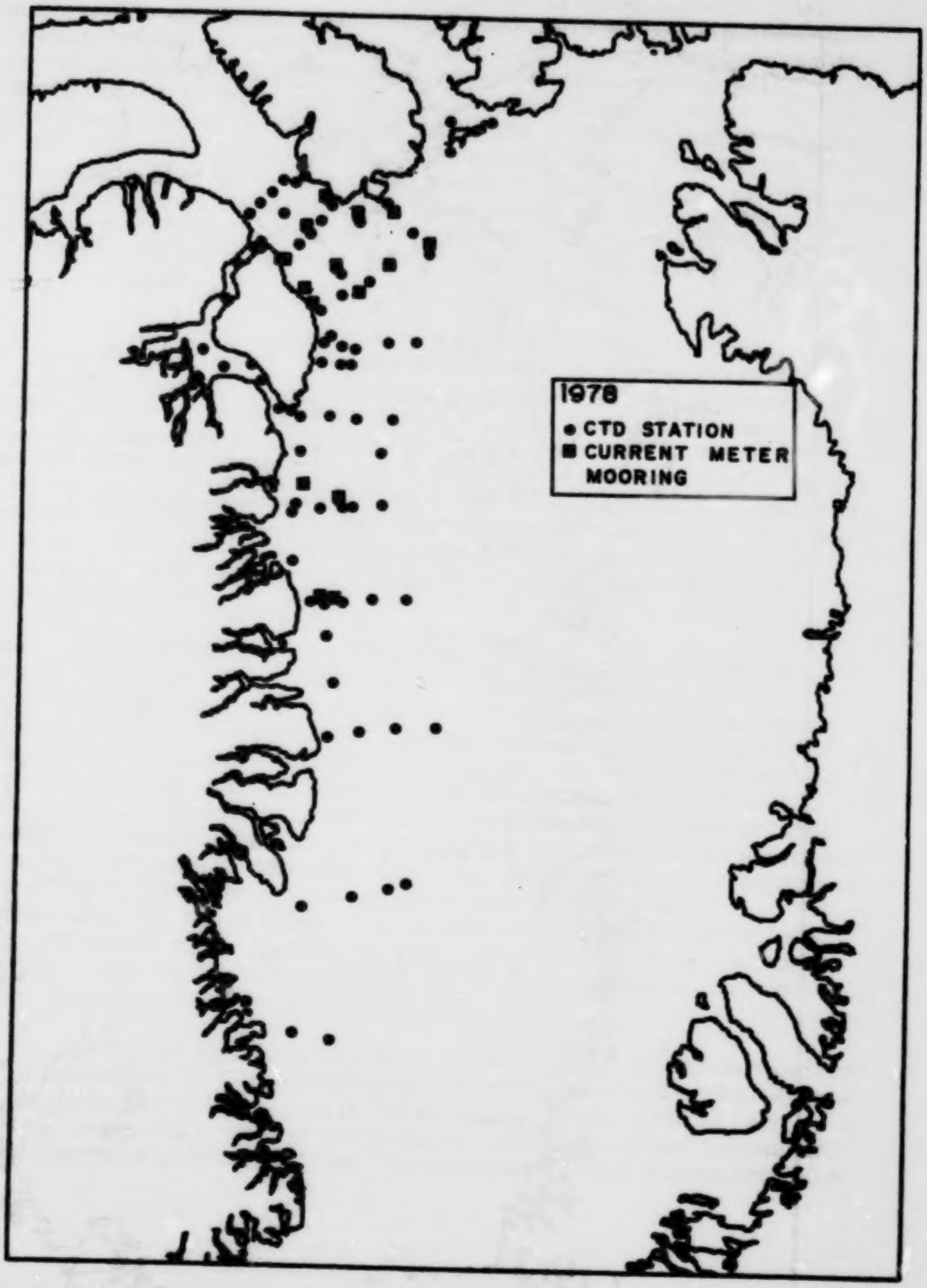

1978
● CTD STATION
■ CURRENT METER MOORING

Figure 1: Locations of current meter moorings and CTD stations in 1978.

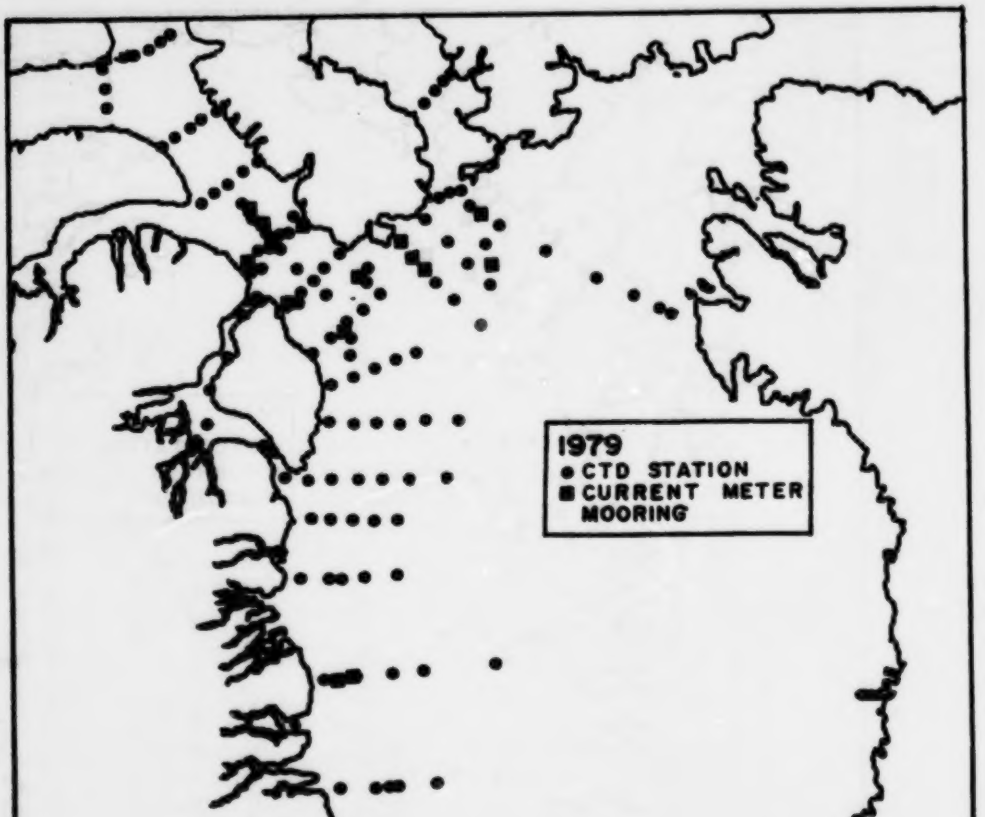

1979
● CTD STATION
■ CURRENT METER MOORING

Figure 2: Locations of current meter moorings and CTD stations in 1979.

On the basis of the 1978 and 1979 summer data, a map has been prepared illustrating the major features of the surface and near-surface circulation (see Figure 3). The displayed flow vectors are scaled according to the average of the observations for that location. It should be kept in mind that, in most locations, the magnitude of the current varies by a factor of two or more about the mean value. Quasi-permanent currents are represented by solid vectors scaled to their mean value but these too can vary significantly with time; in this case, the direction seldom changes by more than thirty degrees but the range of speed variability extends from near zero to several times the mean value. Circulation features which are transient but which have been observed to occur repeatedly are represented with open arrows, while locations where the flow patterns are always found to be different are indicated by special symbols.

It should be noted that the circulation map is limited to the near-surface levels, as deduced from the uppermost current meter records at a nominal depth of 35 m, velocities of satellite-tracked drifters whose drogues extend from 4 to 11 m depths, and charts of surface dynamic heights relative to the 300 decibar level as computed from the CTD data. The illustrated circulation of Figure 3 is by no means an exhaustive compilation of all possible circulation features, but merely an attempt to summarize the more dominant flow patterns. Some parts of the study area warrant a more detailed presentation than is possible in a single map encompassing the entire study area.

As a further aid in the description of the circulation, several regions or sub-areas have been identified where the circulation appears to have a common feature or pattern dominating the local flow. The boundaries of these regions are indicated in Figure 3 by the lightly shaded broad lines; the regions themselves are designated by circled numbers. As well, the areas within 10 kilometres of the coastline are darkly shaded; this differentiates between the offshore and nearshore circulation zones. The width of the nearshore zone is somewhat arbitrary since the present study was limited to field observations at three nearshore sites. Nevertheless, it seems clear that significant differences include increased small scale spatial variability, enhanced tidal motions, and motion due to the existence of local wind regimes which can differ markedly throughout the nearshore zones.

The circulation of the Arctic water layer in western Baffin Bay is dominated by the southeastward flowing Baffin Current (Figure 3). Originating primarily with Arctic Ocean water flowing into northern Baffin Bay through Smith Sound, Jones Sound and Lancaster Sound, the Baffin Current flows southeastward along the western side of Baffin Bay into Davis Strait. The current is stronger near the coast than in the middle of the Bay with the most intense flows generally confined to within 100 km of the coastline. Though the net flow is southeastward, the path of the Baffin Current is characterized by a number of perturbations, some of which are transient in nature while others appear to be more or less permanent features. Perhaps the most striking of these is the intense but relatively narrow intrusive flow into eastern Lancaster Sound. A summary of the major circulation features of the study area is presented below on a regional basis beginning at the northern most part of the study region.

Off the entrance to Jones Sound, the circulation is dominated by a southeasterly outflow from the Sound into Baffin Bay through Lady Ann Strait. The near-surface coastal flow off northeast Devon Island reaches speeds of up to 60 cm/s. Further offshore, the currents are variable as to direction, with net flow to the southwest of about 10 cm/s near the surface.

Further to the south off Philpots Island, the current strengthens to a strong flow about 25 km wide centered 20 to 25 km east of Philpots Island. The surface flow in the core of the current, during summer, is about 40 cm/sec but occasionally reaches 60 cm/sec. The current speeds reduce with depth, to speeds on the order of 5 cm/sec at 250 m depth. Flow reversals can occur near the inshore edge of the current off Philpots Island. The offshore edge of the current in the same area was characterized by a large scale meander in 1979. Some evidence also exists for the presence of a similar feature during the 1978 season.

To the southeast of Philpots Island, the flow turns to the southwest, converging and intensifying just to the east of Cape Sherard. Speeds up to 100 cm/s are achieved as the main core of the current rounds the Cape some 20 km offshore.

The circulation of eastern Lancaster Sound is dominated by the flow of water from east of Devon Island intruding into the Sound on its northern side. This water crosses southwards through the Sound at distances of 35 to 75 km from the eastern boundary and exits again into Baffin Bay along the northwest coast of Bylot Island, with a minor outflow south through Navy Board Inlet. The velocities associated with the intrusive current are generally strong near the surface, decreasing with depth: typical near-surface (4 to 11 m) velocities are 75 cm/s decreasing to 50 cm/s at 40 m depth, 25 cm/s at 250 m depth and 14 cm/s at 500 m depth. Often the current extends to the bottom of eastern Lancaster Sound, which is less than 800 m in depth.

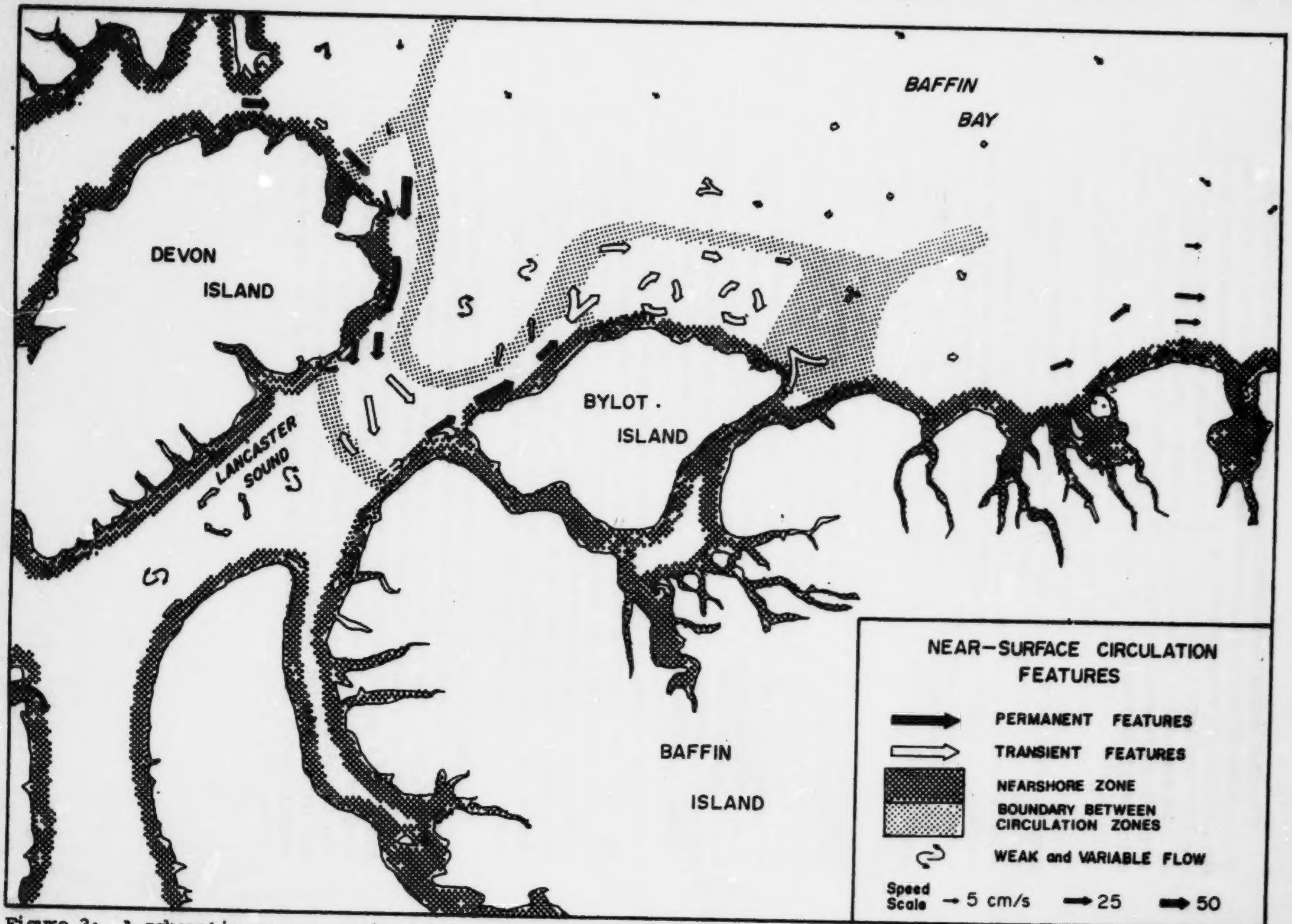

BAFFIN
BAY
DEVON
ISLAND
LANCASTER
SOUND
BYLOT
ISLAND
BAFFIN
ISLAND
NEAR-SURFACE CIRCULATION
FEATURES
PERMANENT FEATURES
TRANSIENT FEATURES
NEARSHORE ZONE
BOUNDARY BETWEEN
CIRCULATION ZONES
WEAK and VARIABLE FLOW
Speed
Scale
5 cm/s
25
50

Figure 3: A schematic representation of the major near-surface circulation features. The circled numbers identify sub-areas of circulation.

The intrusive current is a permanent feature of the summer circulation of eastern Lancaster Sound. It was present at all times when sufficient measurements were available for its resolution in the 1978 and 1979 studies. A review of historical oceanographic data in the region shows that the current's presence was consistent with the derived circulation patterns for eight out of nine years in which sufficient data are available.

Important spatial and temporal variations occur in the intrusive current. With the detailed 1979 data set, it was found that the current has two modes of cross-Sound spatial patterns, characterized by either southeastwards movement towards northwest Bylot Island or south to southwestwards flow towards Borden Peninsula. Supporting evidence for this variation was found in the summer data of Fissel and Wilton (1978). The intrusive current alternates between the two modes, typically persisting in either mode for a period of several days.

The flow off Borden Peninsula is characterized by complex circulation features, apparently a result of the intrusive current meeting the outflow of Arctic Water passing through Lancaster Sound from the west. Lacking sufficiently detailed observations in this area, it was not possible to delineate a complete description of the circulation. However, patterns observed included an easterly flow in mid-Sound accompanied by an anti-cyclonic gyre off the Borden Peninsula; an easterly flow along the Borden Peninsula coastline; and an anti-cyclonic loop extending from the northwestern tip of the Borden Peninsula into the northern half of Lancaster Sound.

The width of the intrusive current appears to increase in the course of its flow through the Sound. In the northern portion, the instantaneous width may be as small as 10 km, but as the current crosses the Sound the upper bound of its width increases to 15-30 km. Upon moving out of the Sound off Bylot Island, even greater widths can occur, presumably due to the combined influence of the intrusive current and the flow from western Lancaster Sound.

Temporal variations at fixed locations in eastern Lancaster Sound are dominated by the major current patterns. Off southern Devon Island, the currents of the intrusive flow are steady in direction with relatively small variations in speed. In the mid-Sound region, the current variations have characteristically long periods (10-30 days) corresponding to the alternating modes of the intrusive current. The temporal variations in the outflow to the north of Bylot Island are relatively large and appear to vary significantly over relatively short spatial scales, on the order of 10 km.

The intrusive currents are associated with oceanic fronts as observed in the water property cross-sections. These fronts, reflecting the large horizontal density gradients which approximately balance the Coriolis force due to the intrusive current, persist throughout the summer coincident with the presence of the intrusive current. They provide a means for enhanced vertical motions due to reduced stratification. Increased upward movement of nutrients may be characteristic of the fronts, resulting in enhanced biological productivity.

To the east of the intrusive current, the circulation off the entrance to Lancaster Sound is characterized by weak disordered flows with speeds on the order of 10-20 cm/sec. Because the flow is extremely irregular, the net movement of the surface waters is small and appears to be directed to the south and east, since all drifters exited the region in these directions. Typical flow speeds are generally reduced to about 8 cm/sec between 250 and 750 m depth, and the direction is steadier and tends toward net westerly movements.

The strong easterly flow on the southern side of eastern Lancaster Sound proceeds along the northern coast of Bylot Island usually becoming detached from the coast at Cape Liverpool. The direction of flow at this point varies from southeasterly, along the coastline, to northeasterly, with the most common direction being easterly. Further downstream the current flows to the southeast, parallel to the eastern Bylot Island coastline but usually 30 to 50 km offshore. This pattern is frequently distorted by large-scale (60 to 70 km) meanders, which sometimes are associated with northerly counter-currents east of the south-tending current. Smaller scale eddies can occur in this offshore zone with rotation in either sense and diameters of 7 to 16 km. Between the coast and the southeasterly current, anti-cyclonic eddies of approximately 20 km diameter are frequently seen. Their rotation period is between 40 and 50 hours, on average. Smaller eddies which may be of either sense of rotation, and have longer periods (55 to 65 hours) are observed outside this zone.

The southeasterly flow turns westward, toward the mouth of Pond Inlet once it reaches the southern end of Bylot Island. This turning generally coincides with the position of a seamount at the southeastern limit of the Bylot Island shelf suggesting that the shallow shelf and its bathymetric features may exert some topographic control over the current.

To the south of Pond Inlet, the southeasterly Baffin Current dominates the water movements of western Baffin Bay along the length of the Baffin Island coastline. South to easterly flows were measured over a wide range of distances from the coast; satellite- tracked drifters were observed moving to the southeast from 2 km to 230 km offshore. The core of the current is located at the edge of the continental shelf and over the most steeply sloping portions of the continental slope. Near-surface velocities have an average value of approximately 30 cm/s in the core of the current, occasionally reaching speeds in excess of 60 cm/s. Further offshore the velocities decrease; at the outer edge of the continental slope, typical velocities of 10 cm/s appear to prevail although occasional much larger values (up to 40 cm/s) have been measured by drifters. The offshore flow shows a tendency to meander somewhat over distances of 35 km across the flow with along-stream length scales of 40 to 120 km. The meander patterns are not permanent but vary with time and location.

The circulation patterns are influenced by the topography along the continental shelf and slope off Baffin Island as demonstrated by the manner in which the core of the current follows the slope regions. On the shelves, the net flow is reduced with average velocities of 12 to 20 cm/s. The speeds of currents on the shelf may be considerable: the largest current measured in this region (85 cm/s) was observed at current meter station 11 located on the shelf. However, the shelf currents are more variable than those over the slope, resulting in reduced net movements.

To the west of the intrusive current in western and central Lancaster Sound, the circulation is highly variable. The net flow through the Sound is eastward but this current varies as to location. At times, easterly flows are confined to the southern side of Lancaster Sound while on other occasions similar movements also occur in mid-channel. As a result of this spatial and temporal variability, the 1979 measurement network was not of sufficient density to determine the persistence of a net eastward flow. Westerly water movements occurred on the north side of the Sound, but were never observed to be continuous or sustained east of 88° west longitude. The most permanent feature of the circulation in this area appears to be an intense (60 cm/s) southeastward coastal current flowing past Prince Leopold Island associated with a cyclonic intrusive current pattern flowing into and out of northern Prince Regent Inlet. There is evidence, though more limited, that a similar intrusive current pattern is present in the mouth of Admiralty Inlet with strong southeastward flows past Cape Crauford. The flow patterns in mid-channel north of the Brodeur Peninsula are often, but not always, characterized by large eddy motions of either cyclonic or anti-cyclonic rotation. From the 1979 observations, the average diameter of the eddies was 26 ± 4 km with average periods of 6 ± 2 days. Similar eddies were observed in 1977 (Fissel and Marko, 1978) with somewhat larger spatial scales.

In the waterway bounding the west and south coasts of Bylot Island, namely the Navy Board Inlet - Eclipse Sound - Pond Inlet system, the net flow tendency is out of Lancaster Sound, emptying into Baffin Bay at the east end of Pond Inlet.

Typical near surface flow speeds are 20 to 30 cm/s. Data in Eclipse Sound are limited but one drifter indicated westerly flow on the north side and easterly flow on the south, with north-south flows evident at both ends of the Sound. In Pond Inlet an intrusive circulation from Baffin Bay was evident in three drifter tracks, with the greatest penetration being 36 km. Inflow was westerly on the north side, with the outflow along the southern side and typical flow speeds of 12-28 cm/s.

The large amounts of freshwater which enter Eclipse Sound due to the melting of sea-ice and land run-off may drive an estuarine circulation. Given the observed tendency of water movement to the south and then east through the Navy Board Inlet Eclipse Sound and Pond Inlet waterway, the fresh water outflow from Eclipse Sound appears most likely to exit the region through Pond Inlet.

A near-surface inflow from eastern Lancaster Sound into Navy Board Inlet was observed from the tracks of two drogued drifters. However, since many other drifters passed through eastern Lancaster Sound without entering Navy Board Inlet, the southward flow into the Inlet appears to constitute but a small fraction of the total outflow from eastern Lancaster Sound.

Temporal Variability of the Circulation

Aside from its described spatial variability the circulation in the study area is also subject to a high degree of temporal change. During the open water period of the summer months, the most important time scales of this change tend to be associated with synoptic variations, inertial oscillations and diurnal and semi-diurnal tidal currents.

In those regions of the study area dominated by strong circulation features such as the Baffin Current, auto-spectra of time series current meter records indicate that synoptic variations account for well over half of the total resolvable variance. The spectral peak due to synoptic variations is very broad, ranging from periods of 2 to 90 days with the largest levels generally occurring at periods between 3 and 30 days. Individual peaks often occur within the broad maximum of the spectral distribution but these features tend not to be of statistical significance due to the limited amount of band averaging which is possible at these long periods (which are large in relation to the record length).

The diurnal and semi-diurnal tidal currents vary significantly throughout the study area, though over larger lengths than the synoptic variations. Harmonic analyses of current meter data reveal that the tidal currents are relatively small; neither the maximum computed amplitude of the largest diurnal (K_1) nor that of the semi-diurnal (M_2) tidal current constituents exceed 8 cm/s at any current meter mooring site outside of the nearshore zone. Since the areas of large K_1 and M_2 components were not coincident, the largest offshore tidal currents, represented as the sum of the two major constituents, are typically 8 to 10 cm/s in amplitude and do not exceed 12 cm/s. In nearshore locations, the tidal currents can be considerably larger. A K_1 internal tide off Cape Hay results in amplitudes of 15 cm/s near the surface. At Cape Crauford, Brodeur Peninsula, a shallow water mooring measured combined K_1 and M_2 tidal currents of 38 cm/s in amplitude.

Inertial oscillations are variations in water currents occurring at the inertial frequency of 2 sin O revolutions per sidereal day, where O is the latitude. In their simplest form, inertial oscillations are circular motions with the sense of rotation being clockwise in the northern hemisphere. Within the study area, these oscillations are at times considerably stronger than the local semi-diurnal tidal oscillations. Typical near-surface amplitudes are 10 to 20 cm/s with speeds as large as 30 cm/s being observed. Inertial oscillations are clearly observed at depths of 4 to 11 m from drifter data and at 35 m from current meter records; at depths of 250 m or more, they are so greatly reduced in amplitude as to be difficult to separate from the tidal variations with any confidence. Thus, large inertial oscillations appear to be confined to the Arctic water mass, concentrated in and immediately below the upper zone.

The properties of inertial oscillations observed over these depth ranges are very clearly related to the local surface wind. They occur intermittently at about the synoptic period of wind variations (3-10 days), and for particularly strong wind events such as that of August 19, 1979 inertial oscillations were generated at a wide range of locations. Once started, inertial oscillations typically persist for a period of 4 to 7 days.

With the successful recovery of five subsurface current meter moorings, operational through the period of extensive ice cover, it became possible in the present study to determine, for the first time, the amplitude and spatial scales of the seasonal variations in the circulation of northwestern Baffin Bay. Significant seasonal changes were evident in the Arctic Water layer currents, temperatures and salinities as measured by current meters at nominal 35 m and 125 m depths. The measured currents were characterized by reduced flow magnitudes in the ice-covered period with minimum values attained in the months February to May. The degree of seasonal current variability at depths of 250 m or greater varied according to location: at one station, seasonal variations were evident to depths of 750 m, while at another station, no significant seasonal differences were limited to depths of 250 m or less. The amplitude of the seasonal variations in temperature and salinity generally decreased with increasing depth. At nominal 400 m depths, these variations in the monthly mean values were less than the accuracy of the measurements.

Nearshore Circulation Features

The description of the circulation features of the study area has, to this point, concentrated on the offshore regime where the water is relatively deep and not immediately adjacent to the coastline. As part of the present study, oceanographic field programs were carried out from land-based camps at three sites in the nearshore zone. These studies indicated that the circulation near the shore differs in some respects from that of adjacent offshore regions. These differences typically persist for distances of approximately 10 km from the shoreline. Often, the circulation in these nearshore zones has complex features with small spatial scales, including eddy-like motions with typical scale sizes of 5 km and accompanying strong lateral velocity shears.

Strong flows in the offshore zone provide a major portion of the current forcing in the immediately adjoining neashore regime. Nevertheless, coastline influences are also evident in the strong lateral velocity shears which appear across the nearshore zone and in the occasional small back-eddy circulation features which would be expected in lateral boundary layers.

The local winds were found to vary significantly with distance offshore at Cape Warrender; winds at the coastline were not representative of winds at locations a few kilometres offshore. As well, strong local winds may develop off some of the glacial valleys and other indentations in the rugged eastern Arctic coastline. These local winds could alter the circulation patterns in the adjacent portion of the nearshore zone.

Tidal currents can be significant in nearshore zones and may be enhanced by internal tides developing in response to the surface tidal motions which drive the stratified nearshore waters over bathymetric gradients. Evidence of such effects is present in the current meter and drogued drifter-data obtained near Cape Warrender, and at the current meter moorings in the Cape Hay vicinity. K_1 tidal effects in both areas were found to be enhanced relative to those observed in adjoining offshore zones.

Freshwater of local origin also may be of importance in determining nearshore circulation features. The freshwater input due to local sea-ice melt or land run-off results in a thin brackish upper layer overlaying a more saline layer of Arctic Water. Along the interface, internal waves develop with periods of the order of 10 minutes. Also, the presence of lateral density gradients resulting from the lower salinity water being concentrated nearshore can result in geostrophic flows. Due to the other driving mechanisms in the area, a simple geostrophic balance may not be attained. However, movement along the geostrophic flow direction could contribute to the net current.

One of the most striking features of the nearshore circulation is the presence of flow opposite in direction to that obtained in the strong currents of the adjacent offshore zone. Instances of such flow reversals were observed at all three nearshore study sites. The reversals do not appear to be permanent, but reflect the changing balance of the forcing mechanisms.

The knowledge gained from studies at these three sites can be used as a guide to anticipate conditions in other areas of the nearshore zone. It should be emphasized that the existing understanding of nearshore processes is far from complete. This incompleteness is evident even in the circulation patterns derived for the Cape Warrender vicinity where the largest sets of nearshore data were gathered. The complicated processes of the nearshore regime clearly require additional study.

Acknowledgements

This study was sponsored by PETRO-CANADA and represents a major component of the multi-disciplinary Eastern Arctic Marine Environmental Studies (EAMES) program, a joint industry-government undertaking.

Many people and organizations assisted us in carrying out our studies. Specifically, we wish to thank:

- Messrs. G. Glazier, H. Hume and Drs. R. Wallace, E.B. Bennett and J.M. Semples of Petro-Canada for their unfailing support and assistance throughout the study.

- Allen Milne and Brian Smiley of the Institute of Ocean Sciences for their assistance in coordinating initial portions of the study and their continuing support.

- Captains Kjell Maro and George Parnell, Chief Officer Karl Egert, Chief Engineer Frank Daw, the officers and crew of the M.V. Theron for their dedication during two extended cruises to Baffin Bay in 1978 and 1979.

- George Koenig, Ray Shurmer, Sandy McKenzie and Paul Idlout of Petro-Canada for their logistical support from the land-base at Pond Inlet, N.W.T.

- Dr. C. Mason, Mr. A.J. Hartling and Mr. Pat Keenan of the Bedford Institute of Oceanography for useful discussions on the use of Aanderaa current meters in Arctic regions.

- Messrs. W.S. Huggett, A. Stickland and R. Bigham of the Institute of Ocean Sciences for advice on current meter mooring techniques.

- Dr. A. Sekerak, R.A. Buchanan, M. Bradstreet, W. Cross, D. Thompson and other members of L.G.L. Environmental Research Associates for their cooperation and assistance with operations from the M.V. Theron and shore-based camps as well as useful discussions on the integrated physical-biological results.

- Mr. H. Serson of Defense Research Establishment Pacific for the loan of some equipment and useful discussions.

- Dr. P. Greisman, formerly with Arctic Sciences Ltd. for useful discussions and the preparation of an early version of portions of Section 3 of this report on the historical survey of physical oceanography.

- Gary Wilton of Arctic Sciences Ltd. who was instrumental in ensuring successful field programs and high data recovery rates.

- Colin Foster, Doug Knight and Doug Say of Arctic Sciences Ltd. for their dedication in processing the large quantity of oceanographic data collected in the course of this study.

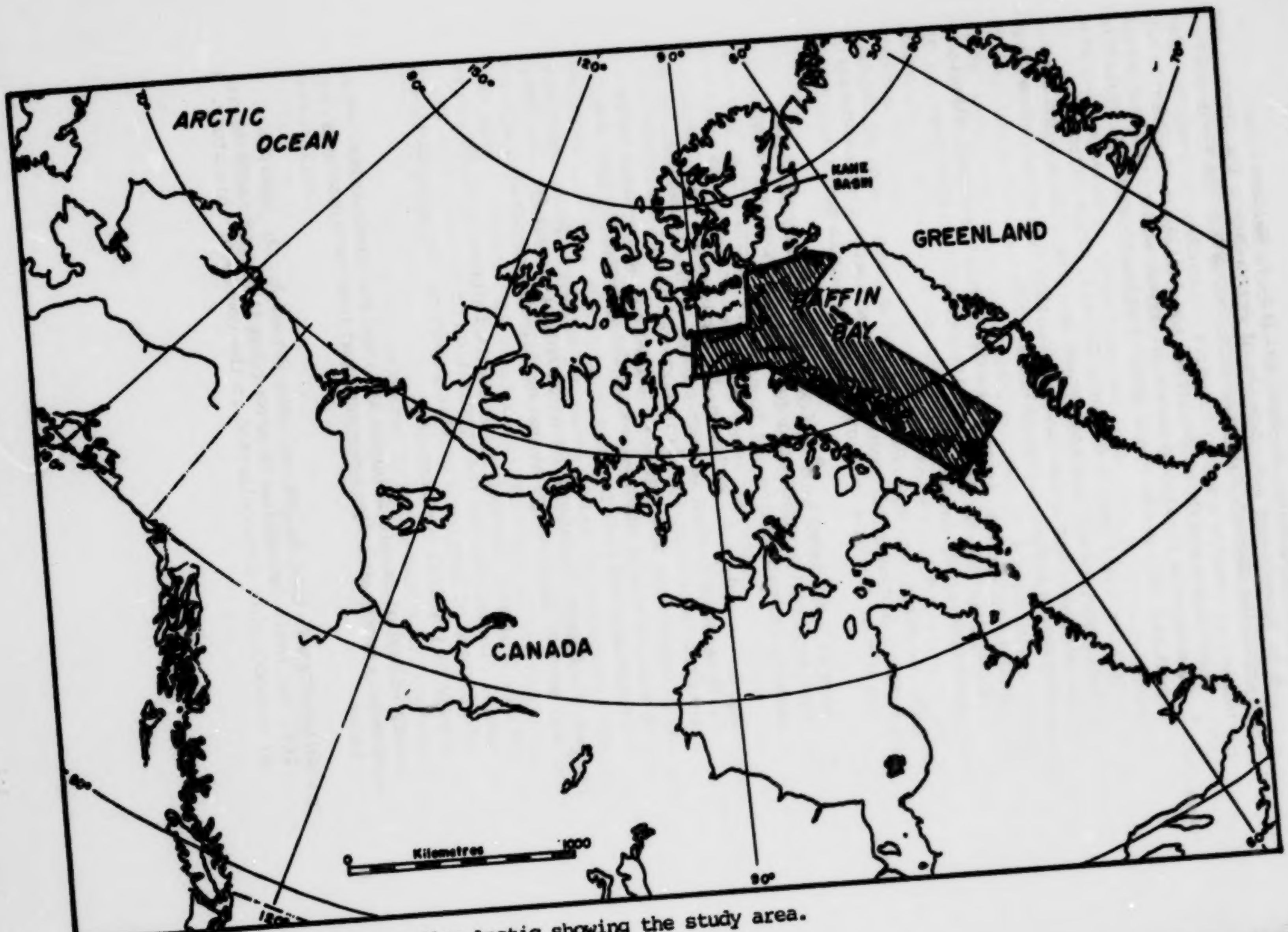

ARCTIC
OCEAN
GREENLAND
KANE
BASIN
BAFFIN
BAY
CANADA
Kilometres
0
1000
150°
120°
90°
60°
30°
80°
70°
60°
80°
90°
120°

Figure 1-1: A map of the Canadian Arctic showing the study area.

TABLE OF CONTENTS

		Page
	EXECUTIVE SUMMARY	i
	ACKNOWLEDGEMENTS	xvi
	LIST OF FIGURES	xxiv
	LIST OF TABLES	xxxviii
1.	INTRODUCTION	1
2.	PHYSICAL SETTING	4
	2.1 Bathymetry	4
	2.2 Ice Cover	4
	2.3 Wind Regime	6
3.	HISTORICAL BACKGROUND	6
	3.1 Introduction	6
	3.2 Early Explorations	7
	3.3 Scientific Investigations, 1860-1970	9
	3.4 Scientific Investigations, 1971-1979	17
4.	PHYSICAL OCEANOGRAPHY FIELD PROGRAMS - 1978 AND 1979	21
	4.1 Subsurface Current Data	22
	4.2 Satellite-Tracked Drifter Data	27
	4.3 CTD Measurements	30
	4.4 Current Profile Measurements	30
	4.5 Water Level Measurements	34
	4.6 Nearshore Physical Oceanographic Studies	34
5.	RESULTS	36
	5.1 Introduction	36
	5.2 Near-Surface Circulation Patterns	41
	5.2.1 Northern Boundary Zone	43
	- Historical Review	43
	- 1978 and 1979 Observations	44

Page

5.2.2 East of Devon Island 50

- Summer 1979 Data 50
- Summer 1978 Data 58
- Summary 60

5.2.3 Intrusive Current in Eastern Lancaster Sound 61

- Introduction 61
- Satellite-Tracked Drifter Data 61
- Circulation Patterns from 1978 and 1979 CTD Data 68
- Current Meter Data: Subsurface Current Distributions 71
- Circulation off Borden Peninsula 76
- Temporal Variations 83
- Width of the Intrusive Current 90
- Depth of the Intrusive Current 92
- Frontal Structures 95
- Summary 98

5.2.4 Central Disordered Zone 99

- Surface Circulation - Summer 1979 99
- Subsurface Currents - Summer 1979 and 1978 109
- CTD Data 109
- Summary 109

5.2.5 Eddy Zone East of Bylot Island 109

- Introduction 109
- General Circulation Pattern 110
- Observations of Eddies East of Bylot Island 123
- Summary 127

5.2.6 East of Baffin Island 127

- Bathymetry and Ice Conditions 128
- Drifter-Deduced Circulation 128
- Circulation Patterns Deduced from CTD Data 133
- Current Meter Data 140
- Summary 142

Page

5.2.7 Western and Central Lancaster Sound 143

- Introduction 143
- Surface Circulation - Pre-1979 Results 143
- Surface Circulation - 1979 Data 148

5.2.8 Navy Board Inlet - Eclipse Sound - Pond Inlet 157
- Drogued Drifter Results 161
- 1979 Current Profiles 163
- 1979 Current Meter Moorings 165
- Summary 165

5.3 Circulation of Atlantic Water in Lancaster Sound 166

5.3.1 Introduction 166
5.3.2 Circulation of the Atlantic Water 166

5.4 Tidal Currents 180

5.4.1 Tidal Heights 180
5.4.2 Accuracy of Tidal Current Analysis 180
5.4.3 M_2 Tidal Currents 183
5.4.4 K_1 Tidal Currents 185
5.4.5 Internal Tides 187
5.4.6 Tidal Currents in Nearshore Zones 187
5.4.7 Summary 190

5.5 Inertial Oscillations 190

5.5.1 Introduction 190
5.5.2 Analysis Techniques 190
5.5.3 Inertial Oscillations at Station 78-13 192
5.5.4 Inertial Oscillations off Eastern Baffin Island 199
5.5.5 Inertial Oscillations off Eastern Devon Island 201
5.5.6 Inertial Oscillations in Eastern Lancaster Sound 207
5.5.7 Inertial Oscillations as Measured by Near-Surface Drifter Tracks 208
5.5.8 Summary 208

Page

5.6 Nearshore Circulation 210

5.6.1 Introduction 210
5.6.2 Methods 210
5.6.3 Cape Warrender Nearshore Zone 212

- Wind Forcing 215
- Tidal Forcing 218
- Surface Circulation 219
- Water Properties 224
- Summary 224

5.6.4 Cape Fanshawe Nearshore Zone 226

- Bathymetry 226
- Water Properties 226
- Surface Circulation 232
- Summary 232

5.6.5 Cape Hay Nearshore Zone 233

- Surface Circulation 233
- Water Properties 237
- Summary 237

5.6.6 Summary of Nearshore Circulation Features 237

5.7 Seasonal Variations 238

5.7.1 Seasonal Variations of Currents 239
5.7.2 Seasonal Variations of Temperature and Salinity 243

5.8 Year-to-Year Variations in the Surface Circulation 247

5.8.1 Lancaster Sound 247
5.8.2 Baffin Island Coast 260

5.9 Water Masses 266

5.9.1 Introduction 266
5.9.2 Upper Zone 267
5.9.3 The Arctic Water - Atlantic Water Interface 277

Page

6. DISCUSSION 281

7. REFERENCES 286

APPENDIX 293

LIST OF FIGURES

Figure		Page
1-1	A map of the Canadian Arctic showing the study area.	xviii
1-2	Place names in (a) the Baffin Bay region and (b) the Lancaster Sound region.	2
2-1	Bathymetry of Baffin Bay and adjacent water bodies.	5
3-1	Tracks of several ice beset vessels and the Polaris floe party (Smith, 1931). Average net speeds are given for major segments of each track.	8
3-2	Dynamic heights calculated relative to 1500 dbar from the 1928 Godthaab expedition and the 1940 Northland expedition.	13
3-3	Locations of Current meter moorings operated in Lancaster Sound in 1974 and 1977.	19
3-4	Paths of satellite-drifters deployed in the summer of 1977 (Fissel and Marko, 1978).	19
4-1	Locations of summer 1978 current meter moorings. Stations marked with a (*) were operating from Oct. 1978 to July 1979 and subsequently recovered.	23
4-2	Locations of summer 1979 current meter moorings.	24
4-3	Operational periods and nominal instrument depths for each current meter mooring in (a) summer 1978, winter 1978 and 1979 and (b) summer 1979.	25
4-4	Times and locations of deployments of 1978 and 1979 satellite-tracked drifters.	29
4-5	Locations of CTD stations in 1978.	31
4-6	Locations of CTD stations in 1979.	32

		Page
4-7	Locations of current profiling stations in 1978.	33
4-8	Locations of current profiling stations in 1979.	33
4-9	Locations of nearshore study areas in the summer of 1979 and the water level gauge operated from August 1978 to May, 1979.	35
5.1-1	Kinetic energy spectra of currents at (a) station 2-35 m depth, (b) station 2 - 125 m depth, (c) station 8a - 35 m depth (d) station 10 - 35 m depth, and (e) station 13 - 35 m depth.	39
5.2-1	A schematic representation of the major near-surface circulation features. The circled numbers identified sub-areas where circulation is discussed in detail in the text.	42
5.2.1-1	Line 2, temperature and salinity structure summer 1979.	45
5.2.1-2	Temperature and Salinity at 5 m depth, in Northern Boundary Zone, Aug. 18 - 22, 1979.	46
5.2.1-3	T-S diagram of CTD stations 1C, 1F and 2G, 1979.	47
5.2.1-4	Vertical cross-sections of temperature and salinity over the upper 100 m of Lady Ann Strait and Glacier Strait, August 20 - 21, 1979.	48
5.2.1-5	Drifter 1976 trajectory, August 18-26, 1979.	49
5.2.2-1	Vertical temperature cross-section from Line 3 of CTD stations, extending east-west off Philpots Island, July 24 - 27, 1979.	51
5.2.2-2	Dynamic Height anomalies (in dynamic cm), relative to 300 dbar reference lever, for three periods in the summer of 1979.	52
5.2.2-3	Detailed chart of the bathymetry in Baffin Bay east of Devon Island and sites of 1979 current meter moorings.	53

Page

5.2.2-4 Velocities of near-surface currents measured by satellite-tracked drifters crossing two sections off Devon Island in 1979. 55

5.2.2-5 Low pass filtered northerly component of velocity at 35 m depth, stations C and D. 57

5.2.2-6 Cross-correlation coefficient (R) versus time lag in days for northerly components measured at stations C and D, 35 m depth. 57

5.2.2-7 Velocities of near-surface currents measured by satellite-tracked drifters crossing two sections off Devon Island in 1978. 59

5.2.3-1 Envelopes containing 1979 drifters tracks divided according to two modes. The cross-hatched areas represent areas common to both modes. Shown separately as dashed lines are the tracks of four drifters which departed from the major flow patterns. 62

5.2.3-2 Near-surface current velocities measured by satellite-tracked drifters through three cross-sections of the intrusive current. The velocities are presented separately for each mode of the current. The symbol (*) represents velocities of drifters deployed in western and central Lancaster Sound. 64

5.2.3-3 Tracks of satellite-track drifters released in 1978. Also shown is the boundaries of the ice pack near the time of the observation. 66

5.2.3-4 Dynamic height anomalies (in dynamic decimetres) relative to 300 dbar level for four periods of CTD observations in 1979: (1) July 18-19 (2) July 29-Aug. 3, (3) September 2-4 and (4) September 14-23. 67

5.2.3-5 Dynamic height anomalies (in dynamic decimetres) relative to 300 dbar lever for three periods of 1978 CTD observations: (1) July 30 - Aug. 20, (2) Sept. 4-7 and (3) Sept. 19-20. 70

Page

5.2.3-6 A comparison of drifter and simultaneous uppermost current meter velocities for separations of 6 km or less. 72

5.2.3-7 Direction distribution of 35 m subsurface currents from 1977, 1978 and 1979 current meter moorings. 73

5.2.3-8 Case studies of simultaneous 1979 drifter and upper current meter velocities suggesting a mode (1) intrusive current pattern. 78

5.2.3-9 Case studies of simultaneous 1979 drifter and upper current meter velocities illustrating (a) anti-cyclonic gyre motions off Borden Peninsula, (b) and (c) mode (2) intrusive current patterns. 79

5.2.3-10 Case studies of simultaneous 1979 drifter and current meter velocities from Sept. 3 to Sept. 9, illustrating transition from mode (1) to mode (2) pattern of intrusive current. 80

5.2.3-11 Schematic representation of repeated circulation patterns in eastern Lancaster Sound. 82

5.2.3-12 Mode pattern of the intrusive current in 1979 as indicated by observational data. 85

5.2.3-13 Low pass filtered currents measured at stations 77-1 and 77-3 by the uppermost current meters. 86

5.2.3-14 Low frequency portion of kinetic energy auto-spectra for uppermost current meter time series at locations in eastern Lancaster Sound. Each spectral band has 10 degrees of freedom. 87

5.2.3-15 Simultaneous tracks of 1979 drifters. 89

5.2.3-16 Auto-and cross-spectral values for uppermost current meter data at stations L and M located off north-western Bylot Island. The 95% significant level for coherence values is shown. 91

		Page
5.2.3-17	Average vertical profiles of the intrusive currents as measured at mooring stations 4, 6, L and M. The horizontal bars represent the extrema of the currents after a low pass filter has been applied to remove daily and higher frequency variations.	93
5.2.3-18	The geostrophic velocity shear computed from CTD normalized to simultaneous direct current meter measurements at 500 m depth.	94
5.2.3-19	The low pass filtered velocities measured at station H at 35, 250 and 500 m depths.	96
5.2.3-20	Evidence of frontal structures in the intrusive current from CTD data from August 23 to September 3, 1979.	97
5.2.4-1	The vector averaged velocities for grid areas in the Central Disordered Zone from 1979 drifter data. The number of individual drifter velocities used in calculating the mean.	100
5.2.4-2	The track of drifter 1980 during the summer of 1979.	101
5.2.4-3	Drifter tracks from 1979 illustrating entry into Central Disordered Zone from Lancaster Sound outflow.	103
5.2.4-4	Dynamic height anomalies (in dynamic cm) relative to 300 dbar for (a) Aug. 31 - Sept. 2, 1979 (along with track of drifter 1976) and (b) Sept. 20-30, 1979 (along with track of drifter 1982).	104
5.2.4-5	Drifter tracks of 1976, 1980 and 1983 leaving the Central Disordered Zone superimposed on the dynamic heights anomaly of Sept. 3-4, 1979.	105
5.2.4-6	The movements of drifters 1975, 1977, 1979 and 1980 from Aug. 18 - 23, 1979 during and after the passage of an intense storm.	106

Page

5.2.4-7 Directional distribution of currents from 35 m current meters at mooring stations 7, 9, 10 and N. 107

5.2.4-8 Surface temperature (°C at 5 m), period of July 29 to August 4, 1979. 108

5.2.5-1 Bathymetry east of Bylot Island (1:2000000 scale). 112

5.2.5-2 Dynamic topography of the surface relative to 300 dbar, 1978. 113

5.2.5-3 Dynamic topography of the surface relative to 300 dbar in 1979. 114

5.2.5-4 Composite of drifter tracks and averaged velocities, August 12-30, 1979. 115

5.2.5-5 Composite of drifter tracks and averaged velocities, August 31 - September 12, 1979. 116

5.2.5-6 Composite of drifter tracks and averaged velocities, September 13 - October 29, 1979. 117

5.2.5-7 Tracks of drifters 1977 and 1983 showing offshore northward counterflow. 118

5.2.5-8 Tracks of drifters 1962 and 1982 showing offshore northward counterflow. 118

5.2.5-9 Drifter tracks through area east of Bylot Island in 1978. 120

5.2.5-10 Track of drifter 1066 past Bylot Island in 1977. 121

5.2.5-11 Track of drifter 1958 from September 12-24, 1979. 124

5.2.5-12 The locations and shapes of eddies as revealed by 1979 drifter tracks. (a) September 9-21 (b) September 27-October 9 and (c) October 13-26. 126

5.2.6-1 Bathymetry of Baffin Bay off the east coast of Baffin Island. 129

		Page
5.2.6-2	Near surface currents measured by 1978 and 1979 drifters through three sections east of Baffin Island. Those velocities marked with a (*) were measured during the formation of new ice.	130
5.2.6-3	Average velocities from 1979 drifter data off the east coast of Baffin Island.	132
5.2.6-4	Drifter tracks off the south-east coast of Baffin Island along with simplified bathymetry.	134
5.2.6-5	Dynamic topography of the surface relative to 300 dbars from 1979 CTD Data.	135
5.2.6-6	Dynamic topography of the surface relative to 300 dbars from 1978 CTD Data.	136
5.2.6-7	Tracks of drifters 1975, 1979 and 1980 located well offshore in the summer of 1979.	138
5.2.6-8	The directional distribution of current meter data at nominal depths of 35 m located off the east coast of Baffin Island, August - September, 1978.	139
5.2.7-1	Surface currents in Western Lancaster Sound as presented by (a) Bailey (1957) and (b) Collin (1962).	144
5.2.7-2	The vector averaged velocities of all 1979 measurements in eastern Parry Channel. The vector averaging is applied over rectangles with dimensions of 0.2 degrees latitude and 0.8 degrees longitude (Fissel and Marko, 1978).	145
5.2.7-3	Dynamic topography of the surface relative to 175 dbar for the period August 24 to September 6, 1979. Contour interval is 2 dynamic cm.	146
5.2.7-4	σ_t section, line 7, August 24, 1979.	147
5.2.7-5	σ_t section, line 7, September 13, 1979.	147

Page

5.2.7-6 Composite plot of averaged drifter velocities August 12 - October 29, 1979. 149

5.2.7-7 Averaged drifter velocities; (a) August 23-30, (b) August 31 to September 12 and (c) September 13 to October 29, 1979. 151

5.2.7-8 Drifter plots for periods (a) August 23-30, (b) August 31 to September 12 and (c) September 13 to October 29, 1979. 154

5.2.7-9 Eddy motions described by drifters in 1979. 156

5.2.8-1 Bathymetry of Navy Board Inlet, Eclipse Sound and Pond Inlet from Canadian Hydrographic Service Chart 7220. Depths are in meters. 158

5.2.8-2 Salinities at 1 m depths for (a) August 15-16, 1979 and (b) September 10-12, 1979. 159

5.2.8-3 Temperatures at 1 m depth for (a) August 15-16, 1979 and (b) September 10-12, 1979. 160

5.2.8-4 Tracks of drifters in Navy Board Inlet, Eclipse Sound and Pond Inlet, in 1979. 162

5.2.8-5 Profiling current meter results, September 10-12, 1979 at 4.6 m and 38 m depth. 164

5.3-1 Longitudinal section of temperatures along the centre of Lancaster Sound below 100 m depth based on August 1979 CTD data. 167

5.3-2 The vector-averaged currents from all current meter moorings in eastern Lancaster Sound. The circled numbers denote the station numbers while the bracketed numbers denote the steadiness factor in order of increasing depths. Each vector is labelled with the mean depth. 168

5.3-3 Horizontal distribution of temperature at 500 m, summer 1979. 170

5.3-4 Vector average currents and direction distributions at 500 m, summer 1979. 171

Page

5.3-5 Temperature cross-section through line 4 (a) July 18, 1979, (b) July 30, 1979, (c) September 2, 1979 and (d) September 19-21, 1979. 172

5.3-6 Temperature time series at (a) station M, 450 m depth and (b) station L, 500 m depth. 174

5.3-7 Vertical cross-sections along Lancaster Sound (a) July 19-22, 1979, (b) July 29 to August 4, 1979 and (c) September 13-29, 1979. 176

5.3-8 Temperature time series at (a) mooring H 500 m depth, (b) mooring J, 500 m depth and (c) mooring K, 500 m depth. 178

5.4-1 Tidal Heights of M2 and K1 constituents in Baffin Bay, after Godin (1966). 179

5.4-2 M2 tidal current ellipses from current meter data. 184

5.4-3 K1 tidal current ellipses from current meter data. 188

5.4-4 Variations of the amplitude of the K1 tidal currents with depth and distance offshore of northwestern Bylot Island. 189

5.5-1 The period of inertial oscillations as a function of latitude. 191

5.5-2 The transfer function of the semi-diurnal band pass filter used in the analysis of inertial oscillations. 193

5.5-3 For the current meter time series data at station 13, 35 m depth, (a) the semi-diurnal passed data, (b) the predicted semi-diurnal tidal current and (c), the difference between (a) and (b) dominated by inertial oscillations. 194

5.5-4 Progressive vector diagram of the inertial oscillations computed for station 13 - 35 m for September 9 - 14, 1978. 195

		Page
5.5-5	The percent exceedance of inertial oscillation magnitudes at (a) station 13 - 35 m and (b) station 13 - 250 m.	197
5.5-6	The semi-diurnal band passed northerly components at 35 m depth at stations 11, 13, 14 and 15 in 1978.	200
5.5-7	The semi-diurnal band passed northerly components at 35 and 125 m depths for stations 11 and 14 in 1978.	202
5.5-8	As in figure 5.5-3, for the 35 m currents measured at station D in 1979.	203
5.5-9	The semi-diurnal band passed easterly current components at stations C, D and E.	204
5.5-10	The semi-diurnal band passed current components at station J for depths of 35 m and 500 m.	205
5.5-11	The tracks of two satellite-tracked drifters during and immediately after a strong wind event on August 18-20, 1979. Inertial oscillations are evident in the tracks of both drifters.	206
5.6.3-1	Location of the nearshore study area at Cape Warrender and tracks of three drifters which left the usual pathway of the intrusive current.	211
5.6.3-2	A composite drawing of large floe ice movements in Lancaster Sound, June 20-22, 1974, from satellite imagery.	213
5.6.3-3	Movement of oil spill followers on August 1, 1979.	213
5.6.3-4	The predicted tidal currents for station G based on harmonic analysis results.	214
5.6.3-5	Track of drifter 1980, August 13-16, 1979.	216

Page

5.6.3-6 For 42 m current data at station G, (a) the easterly component, (b) predicted easterly tidal component, (c) difference between (a) and (b): the non-tidal variations and (d) the predicted tidal height based on water level gauge data at Johnson Bay. 216

5.6.3-7 Composite of all oil-spill follower trajectories, July 25 to August 6, 1979, following removal of effects of wind and tidal currents. Velocities labelled on tracks are in cm/s. 217

5.6.3-8 Trajectories of oil-spill followers on August 14, 1979. Velocities labelled on tracks are in cm/s. 217

5.6.3-9 Aerial photograph of coastline between Capes Sherard and Warrender taken in 1959 from 30,000 feet altitude. Small ripple like features are believed to be internal waves. 220

5.6.3-10 CTD profile at station 8 km east of Cape Warrender and 2 km from shore, August 7, 1979. 221

5.6.3-11 Surface temperature and salinity distribution off Cape Warrender, August 7-8, 1979. 222

5.6.3-12 Vertical section of temperature and salinity through section A-A' shown in Figure 5.6.3-11. 223

5.6.4-1 Trajectories of drogued drifters passing near Cape Fanshawe Study area. 225

5.6.4-2 Temperature profile at station off Cape Fanshawe, August 29, 1979. 227

5.6.4-3 Vertical cross-section of temperatures offshore from Cape Fanshawe. 228

5.6.4-4 Composite of oil spill follower tracks in Cape Fanshawe nearshore study area. Also shown is track of drogued drifter 1974. 229

5.6.4-5 The movement of shore ice past Cape Fanshawe on August 22, 1979. Also shown are the simultaneous movements of oil spill followers. 230

		Page
5.6.5-1	Tracks of drifters passing near Cape Hay nearshore study area.	231
5.6.5-2	Aerial photograph of Cape Hay nearshore study area taken on August 28, 1958 from 30,000 feet.	234
5.6.5-3	Tracks of two oil spill followers off Cape Hay, September 6, 1979.	235
5.6.5-4	Vertical section of temperatures and salinities along section indicated in Figure 5.6.5-3.	236
5.7-1	Monthly vector-averaged velocities of current meter data from August 1978 to July 1979. The orientation of the vectors is indicated by the direction of geographical north in each plot.	240
5.7-2	The currents at station 2 after low pass filtering to remove daily and higher frequency variations.	241
5.7-3	Monthly mean temperatures of current meter data from August 1978 to July 1979. The numbers beside each time series indicate the actual mean depth of the current meter.	244
5.7-4	Monthly mean salinities of current meter data from August 1978 to July 1979. The numbers beside each time series indicate the actual mean depth of the current meter.	245
5.8-1	Dynamic topography of the surface relative to 300 dbar, August 2-12, 1954 in Lancaster Sound.	249
5.8-2	Dynamic topography of the surface relative to 300 dbar, September 23 to October 1, 1956 in Lancaster Sound.	250
5.8-3	Dynamic topography of the surface relative to 300 dbar, August 20 and September 18-25, 1959 in Lancaster Sound.	250
5.8-4	Dynamic topography of the surface relative to 300 dbar, September 15-24, 1960 in Lancaster Sound.	251

		Page
5.8-5	Dynamic topography of the surface relative to 300 dbar, September 13-19, 1961 in Lancaster Sound.	252
5.8-6	Dynamic topography of the surface relative to 300 dbar, October 2-7, 1962 in Lancaster Sound.	253
5.8-7	Dynamic topography of the surface relative to 300 dbar, October 3-7, 1963 in Lancaster Sound.	254
5.8-8	Dynamic topography of the surface relative to 300 dbar, July 24 to August 6, 1970 in Lancaster Sound.	255
5.8-9	Dynamic topography of the surface relative to 500 dbar, 1966 (Muench, 1971) in Lancaster Sound.	256
5.8-10	Dynamic topography of the surface relative to 500 dbar, September 17-25, 1960 in Western Baffin Bay.	261
5.8-11	Dynamic topography of the surface relative to 500 dbar, September 15 to October 2, 1961 in Western Baffin Bay.	261
5.8-12	Dynamic topography of the surface relative to 500 dbar reference level, October 5-16, 1962 in Western Baffin Bay.	262
5.8-13	Dynamic topography of the surface relative to 500 dbar reference level, September 5 to October 8, 1964 in Western Baffin Bay.	262
5.8-14	Dynamic topography of the surface relative to 500 dbar reference level, September 24 to October 10, 1968 in Western Baffin Bay.	263
5.8-15	Dynamic topography of the surface relative to 500 dbar reference level, October 4-15, 1969 in Western Baffin Bay.	263
5.9-1	Line 13, August 25-26, 1979. Temperature cross-section, upper 100 metres.	268
5.9-2	Line 13, August 25-26, 1979. Salinity cross-section, upper 100 metres.	269

		Page
5.9-3	Examples of types of upper layer structures observed in 1979.	271
5.9-4	Successive temperature, salinity and σ_t profiles at offshore station 20, in 1979.	272
5.9-5	Histogram of first strong pycnocline depth for all 1979 casts.	273
5.9-6	Depth of the mixed layer for all 1979 CTD stations plotted as a function of observation time; (a) July 17 to September 4 and (b) September 5 to October 15, 1979.	274
5.9-7	Scatter plot of the mixed layer depth versus surface salinity.	276
5.9-8	An example of a station with no interleaving in the Arctic - Atlantic interface.	278
5.9-9	An example of a station with no interleaving of temperatures in the Arctic - Atlantic water interface.	279
5.9-10	The distribution of temperature interleavings in the Arctic - Atlantic interface, summer 1979.	280

LIST OF TABLES

Table		Page
3-1	A summary of oceanographic expeditions in Baffin Bay, Lancaster Sound and Jones Sound, 1928 - 1970.	16
4-1	The accuracy of sensors on the Aandera RCM-4 curent meter, as provided by the manufacturer.	27
5.2.3-1	Velocities of the intrusive current in Lancaster Sound through three cross-sections, based on 1979 drifter velocities. The velocities are tabulated for both modes.	63
5.2.3-2	Summary of current meter measurements from the uppermost current meter at sites located in the intrusive current.	75
5.2.3-3	A listing of the mode of the intrusive current for various periods for summer 1979.	84
5.2.5-1	Summarized characteristics of all the eddies observed during 1979 in the tracks of the drifters passing east of Bylot Island.	122
5.2.5-2	Summer 1979 drifter tracks which showed no eddy motion in the area east of Bylot Island.	123
5.2.6-1	Statistics of the uppermost current meter measurements off the east coast of Baffin Island.	141
5.2.7-1	Characteristics of eddies north of Brodeur Peninsula.	157
5.3-1	Current data at 500 metres, summer 1979, for stations G to M.	169
5.4-1	Parameters of the M_2 tidal current ellipse and information on the measurement sites as to location and period of data collection.	182
5.4-2	Parameters of the K_1 tidal current ellipse and information on the measurement sites as to location and period of data collection.	186

Page

5.8-1 Data used for year-to-year comparisons, comprising of year, number of stations and dates of occupation. 248

5.8-2 Extent of westward penetration in each year between 1928 and 1979 for which an intrusive current was definitely present. 258

5.8-3 Surface current speeds based on geostrophic calculations in the intrusive current (relative to the reference level of 300 dbar) of data prior to 1970. 259

5.8-4 Summary of the characteristics of the eddies found in the data in Table 5.8-3. 260

5.8-5 Summary of the data used for the year-to-year comparisons in the Baffin Current. 264

5.8-6 Typical and maximum surface speeds in the Baffin Current based on geostrophic calculations. 265

5.8-7 Direction of flow between Cape Graham Moore and Cape Jameson. 266

1. INTRODUCTION

In 1978 and 1979, ARCTIC SCIENCES Ltd. carried out a program of physical oceanographic measurements in Lancaster Sound and Baffin Bay on behalf of Petro-Canada. This project was part of the Eastern Arctic Marine Environmental Studies (EAMES) program, a cooperative industry-government undertaking which covered a wide range of biological, oceanographic, meteorological and ice studies. This report concerns the physical oceanographic segment of the program.

The physical oceanographic studies described in this report were designed to provide information for the assessment of the environmental risk in exploratory drilling in Baffin Bay and Lancaster Sound. The program was intended as an intensive general circulation study of western Baffin Bay and Lancaster Sound. Some site-specific studies were included, but the main purpose of the work was to fill gaps in the existing knowledge of the circulation of the area.

Figure 1-1 shows the location of the study area, while Figure 1-2 is a more detailed map which gives place names used in this report. The measurements carried out in this area have been used to describe the surface and near-surface circulation of Lancaster Sound and western Baffin Bay, and to refine the existing knowledge of their water masses.

This report contains a brief discussion of the physical setting of the study area, a brief review of previous oceanographic knowledge and a description of the 1978 and 1979 field program. The results of the measurements are presented as a description of the surface circulation. The study area has been divided into zones of similar characteristics and the circulation has been described in some detail for each one.

Emphasis has been given to a description of the surface and near-surface circulation this being the most relevant set of results for the purposes of the study. The deeper circulation is touched upon lightly, as are the more striking temporal variations. As well, some conjectures about the dynamics controlling the observed circulation have been made. Further analysis, although not necessary for the immediate purposes of the environmental assessment, is certainly possible with a large data set such as this. The data collected in the course of this study have been summarized in a series of data reports. A list of these data reports is provided in the Appendix.

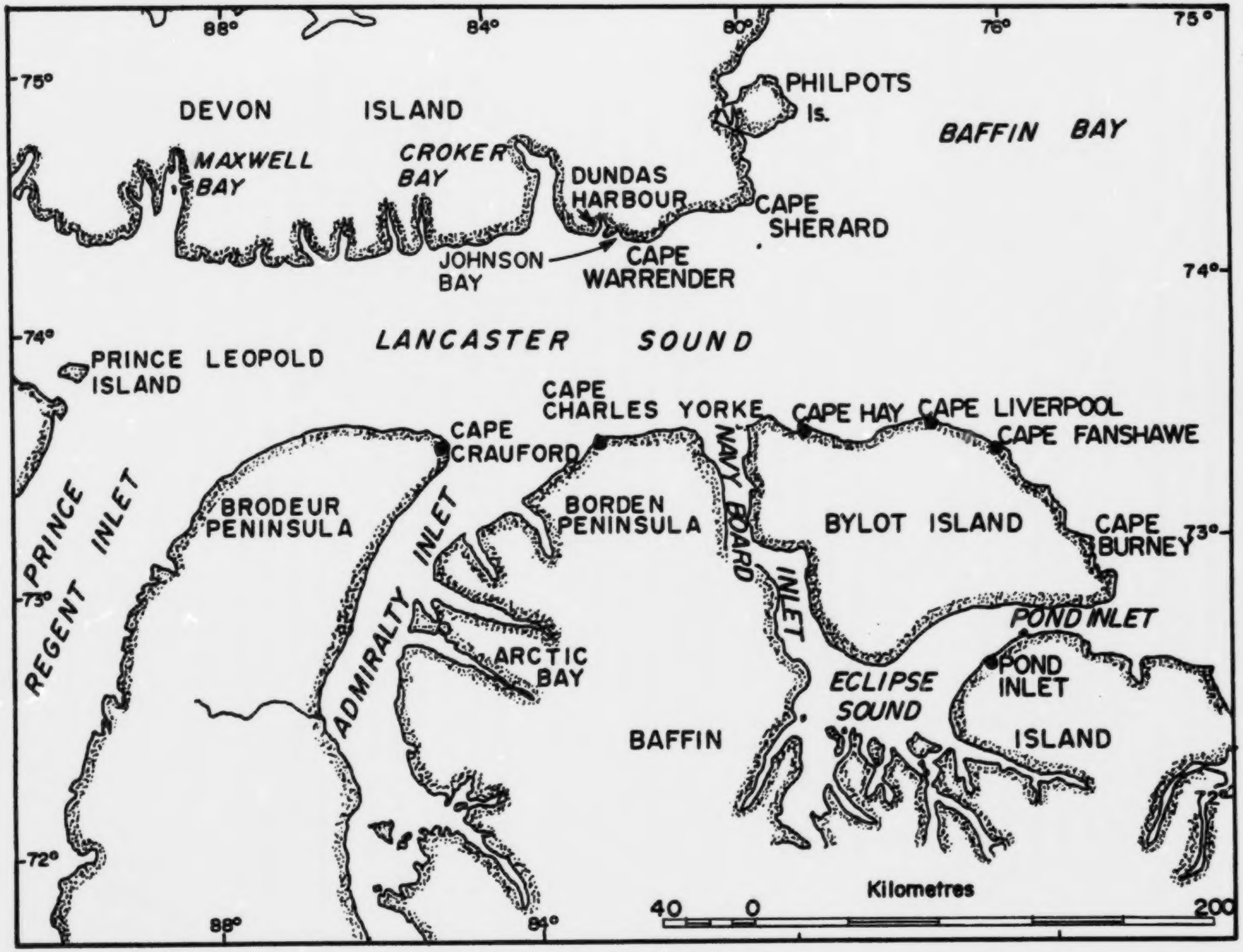

88°
84°
80°
76°
75°
-75°
74°
-74°
73°
-73°
72°
-72°
DEVON ISLAND
MAXWELL BAY
CROKER BAY
DUNDAS HARBOUR
JOHNSON BAY
CAPE WARRENDER
PHILPOTS Is.
CAPE SHERARD
BAFFIN BAY
LANCASTER SOUND
PRINCE LEOPOLD ISLAND
PRINCE REGENT INLET
BRODEUR PENINSULA
CAPE CRAUFORD
ADMIRALTY INLET
ARCTIC BAY
CAPE CHARLES YORKE
BORDEN PENINSULA
NAVY BOARD INLET
CAPE HAY
CAPE LIVERPOOL
CAPE FANSHAWE
BYLOT ISLAND
CAPE BURNEY
POND INLET
POND INLET
ECLIPSE SOUND
BAFFIN ISLAND
Kilometres
40
0
200

Figure 1-2 (a): Place names in the Lancaster Sound region.

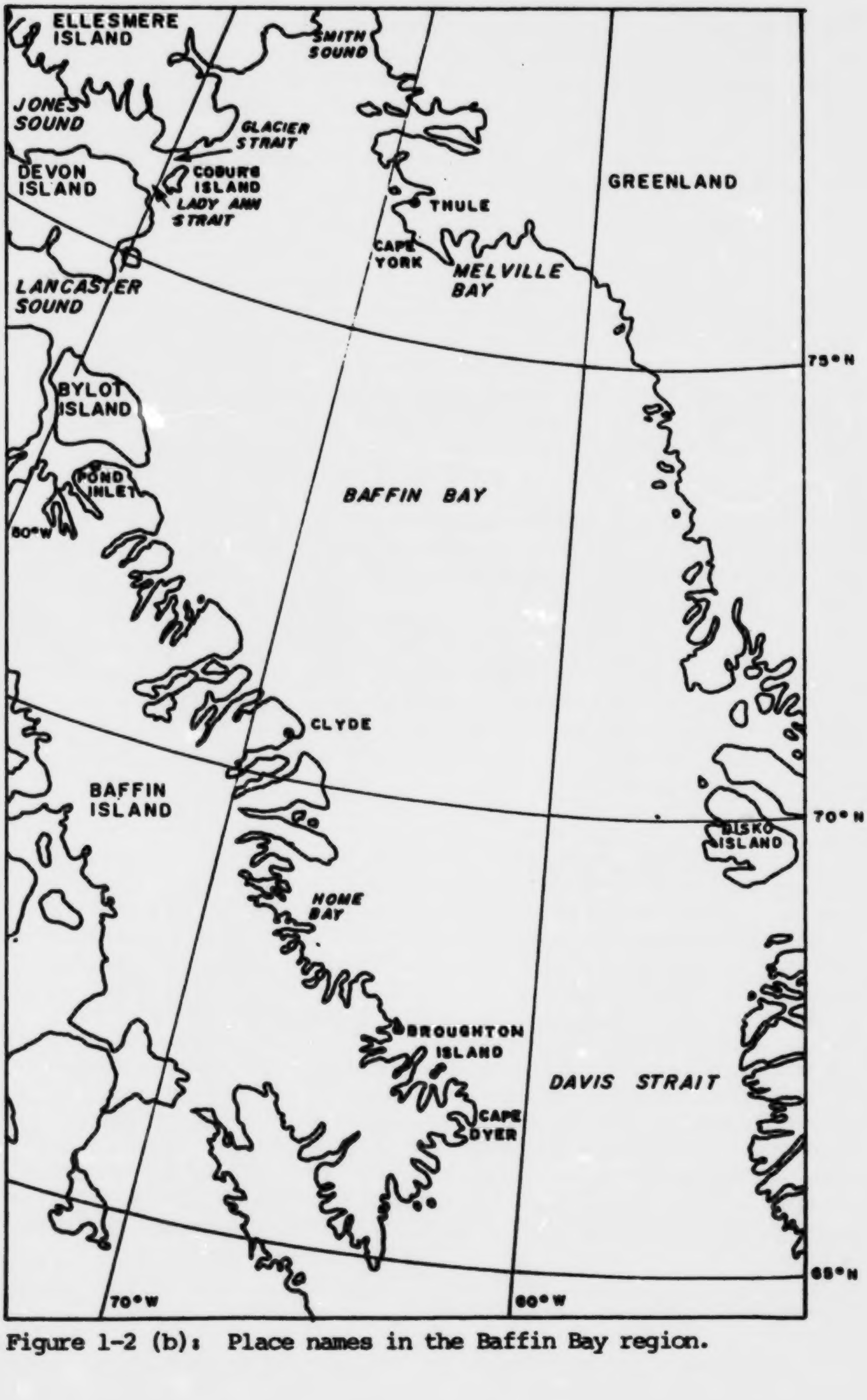

ELLESMERE ISLAND
SMITH SOUND
JONES SOUND
GLACIER STRAIT
DEVON ISLAND
COBURG ISLAND
LADY ANN STRAIT
GREENLAND
THULE
CAPE YORK
MELVILLE BAY
LANCASTER SOUND
75° N
BYLOT ISLAND
POND INLET
80°W
BAFFIN BAY
CLYDE
BAFFIN ISLAND
70° N
DISKO ISLAND
HOME BAY
BROUGHTON ISLAND
DAVIS STRAIT
CAPE DYER
65° N
70° W
60° W

Figure 1-2 (b): Place names in the Baffin Bay region.

2. PHYSICAL SETTING

Lancaster Sound and western Baffin Bay are wholly within the High Arctic. Baffin Bay is bounded on the east by Greenland and on the west by the islands of the Arctic Archipelago. Lancaster Sound, separating Bylot and Baffin Islands from Devon Island, is a 100 km-wide strait, leading west from Baffin Bay, forming the eastern portion of Parry Channel. The islands are mountainous (elevations up to 1500 m) and heavily glaciated. Their coastlines are indented by numerous fiords.

2.1 Bathymetry

Figure 2-1 is a bathymetric chart of Baffin Bay and its surroundings, abstracted from the General Bathymetric Chart of the Oceans series. The centre of Baffin Bay consists of a flat-bottomed basin of more than 2300 m depth. The basin is bounded on the west by a relatively narrow, steep-sided shelf along the east coast of Baffin Island. Water depths are generally less than 200 metres on the shelf, although it is cut by several trenches whose depths are up to 800 metres. The deep basin shoals more gradually to the northwest into the entrance of Lancaster Sound, where depths at the eastern end average 700-800 metres. Lancaster Sound itself has steep sidewalls and gradually shoals westward to a sill of less than 200 metres depth in Barrow Strait.

East of Devon Island a broad bank with depths of less than 350 m is partially separated from the east coast of Devon Island by a trench up to 600 metres deep which issues from Jones Sound via Lady Ann Strait. The trench ends at Philpots Island. The east side of the bank is bounded by the channel extending southward from Smith Sound. This channel is limited by a 250 m sill in Kane Basin.

2.2 Ice Cover

With the exception of the North Water, Lancaster Sound and western Baffin Bay are covered with pack ice throughout the winter season. The dynamics and extent of the pack ice are dealt with in detail in a separate report (Marko, 1980). A brief overview of general ice conditions in the area will be given here. Clearing usually begins in late June, with the expansion of the North Water to the south and west into the mouth of Lancaster Sound. The further clearing of Lancaster Sound and Barrow Strait depends upon the position at which the commonly observed edge between landfast ice and mobile sea-ice has been established during the previous winter (Marko, 1977). The edge may stabilize at one or more locations between Cape Warrender and Barrow Strait. East of the edge, Lancaster Sound becomes almost entirely ice-free until the ice edge breaks down and allows further discharges of ice from the west. These discharges take the form of ice streams and variously

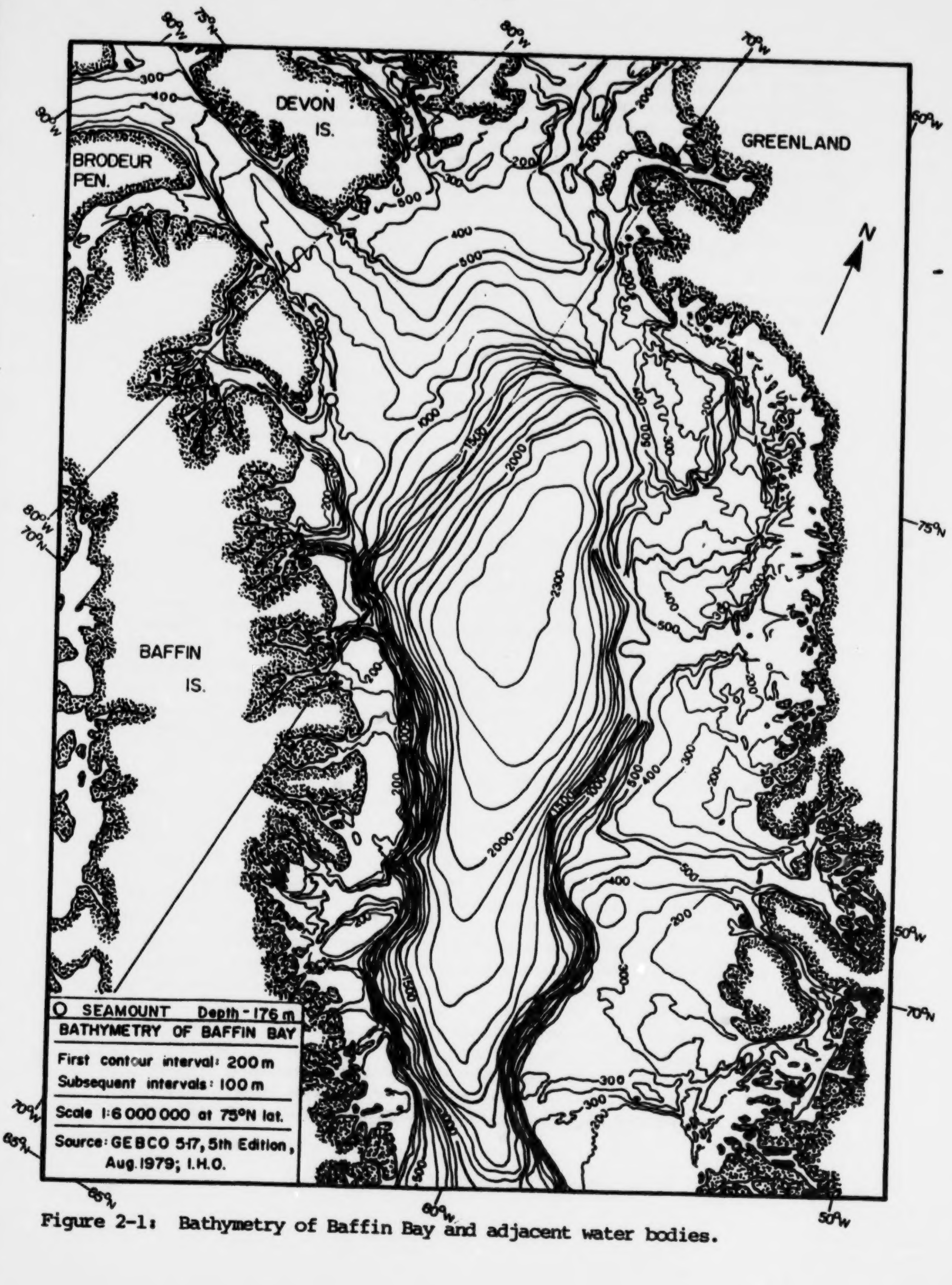

DEVON IS.
GREENLAND
BRODEUR PEN.
BAFFIN IS.
N
80°W
75°N
70°W
60°W
50°W
70°N
65°N
O SEAMOUNT Depth - 176 m
BATHYMETRY OF BAFFIN BAY
First contour interval: 200 m
Subsequent intervals: 100 m
Scale 1:6 000 000 at 75°N lat.
Source: GEBCO 5-17, 5th Edition, Aug. 1979; I.H.O.
200
300
400
500
1000
1500
2000
2300

Figure 2-1: Bathymetry of Baffin Bay and adjacent water bodies.

sized ice fields. Baffin Bay clears from the north and east, leaving most of the bay clear by early September, with the possible exception of a remnant of the pack in the centre of the bay, and a coastal strip along Baffin Island. The ice along the Baffin coast is generally the last to clear and in some years, never clears. Throughout the generally ice-free season, discharges of pack ice occur into Baffin Bay from the passages of the archipelago, and, of course, icebergs are ubiquitous in the western half of the bay.

Both 1978 and 1979 were severe ice years, 1978 being worse than 1979. In 1978, the ice edge in Lancaster Sound stabilized at Cape Warrender and remained there until late August. After its disintegration, discharges of ice from the archipelago produced significant amounts of pack ice in eastern Lancaster Sound and along the Bylot and Baffin Island coasts. In 1979 the Lancaster Sound ice edge stabilized further to the west off Croker Bay and broke up earlier, but the position was still relatively far to the east. Again, discharges of ice from the archipelago occasionally resulted in heavy concentrations of pack ice in Lancaster Sound and along the Baffin coast.

2.3 Wind Regime

The analysis of the meteorological data collected during the field programs is not yet available, therefore this section will offer only a brief climatological overview of the Baffin Bay wind regime. Maxwell et al (1980) have described the prevailing summer-fall wind regime over northwestern Baffin Bay as being variable in direction in July and August, characterizing a weak pressure gradient. In early September a stronger northerly flow becomes established which prevails through the remainder of the fall. Higher wind speeds occur in September and October, caused by the autumn increase in cyclonic activity over northwestern Baffin Bay.

3. HISTORICAL BACKGROUND

3.1 Introduction

Our previous knowledge of the physical oceanography of Baffin Bay and the adjoining water bodies including Lancaster Sound and Jones Sound is based on oceanographic measurements dating from well over one hundred years ago up to the present. In spite of the length of time over which measurements have been collected in the area, knowledge of the region's physical oceanography has lagged behind that of more temperate Canadian water bodies. This reduced level of knowledge can be explained by the remoteness of the region, making oceanographic surveys relatively expensive and perhaps, of less direct interest to the southern-based population. Another significant factor is the increased difficulty of working in ice infested waters; the navigational season is limited to a few months each year and varies significantly and unpredictably from one year to another.

In spite of these difficulties, a sizeable amount of information on the physical oceanography of the area has been collected. This information has been summarized in earlier works including those of Dunbar (1951), Dunbar et al. (1967), Muench (1971) and Walker (1977). In this section, we shall present a brief and updated review of the physical oceanography. For more detail, the reader is referred to the earlier reviews cited above.

A chronological review can be divided into three fairly distinct periods:

1. Up to the year 1860, when very limited amounts of oceanographic data were collected as part of the first voyages of exploration to the region.

2. From 1860 to 1970: voyages of scientific inquiry replaced those of the early explorers.

3. From 1970 to the present: the advent of new technology enabled oceanographers to carry out direct measurements on a much greater scale than ever before possible.

3.2 Early Explorations

This initial period of exploration can be traced back to the voyages of the Norse to the area as early as the tenth century. The first discoveries which have survived in written form were those of the English expeditions searching for the Northwest Passage to the Orient in the late sixteenth and early seventeenth centuries. In 1616, Bylot and Baffin reached the northern limit of Baffin Bay and sighted Lancaster and Jones Sounds.

After a period of relative inactivity for 200 years, the search for the northwest passage was resumed by the British in 1818. This era of exploration culminated in the loss of the Franklin expedition in 1846 and with the subsequent expeditions dispatched in search of this ill-fated venture over the next ten years. By the end of this period, the knowledge of the geography of Baffin Bay and its adjoining water bodies was relatively complete.

As part of these early voyages, a limited amount of oceanographic data was collected. Sir John Ross took the first measurements of subsurface temperatures and salinities in 1818 and scattered observations were collected on later voyages. Because of the very limited amount of data and the lack of understanding of the types and origin of water masses in the area at that time, these early data were of limited value. More important were observations of the drift of sea-ice, icebergs and vessels beset in the ice which provided the first evidence of a southeasterly current in western Baffin Bay and an easterly flow in Lancaster Sound, as shown in Figure 3-1.

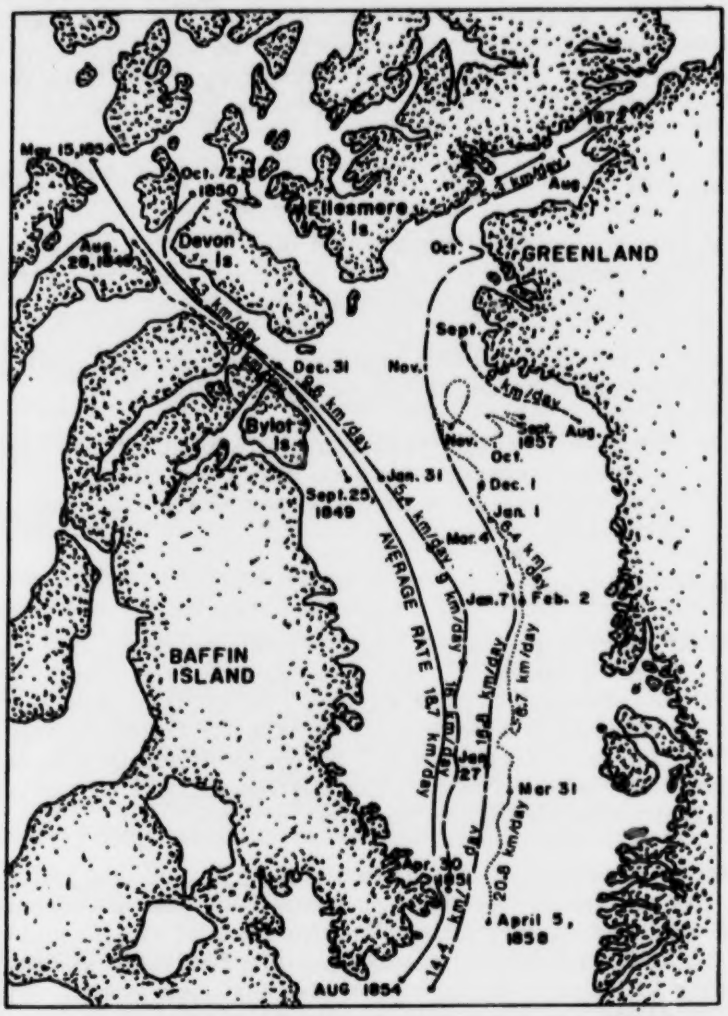

May 15,1854
Oct. 2,
1850
Ellesmere
Is.
1872
km/day
Aug.
Devon
Is.
Aug.
28,1849
Oct.
GREENLAND
km/day
Sept.
Dec. 31
Nov.
8.6 km/day
km/day
Bylot
Is.
Sept.
1857
Aug.
Nov.
Oct.
Jan. 31
Dec. 1
Sept.25,
1849
5.4 km/day
Jan. 1
Mar. 4
6.4 km/day
AVERAGE RATE 18.7 km/day
9 km/day
Jan.7
Feb. 2
BAFFIN
ISLAND
16 km/day
19.4 km/day
6.7 km/day
Jan.
27
Mar 31
20.8 km/day
Apr. 30
1851
14.4 km/day
April 5,
1858
AUG 1854

Figure 3-1: Tracks of several ice beset vessels and the Polaris floe party (Smith, 1931). Average net speeds are given for major segments of each track.

3.3 Scientific Investigations, 1860-1970

With the discovery and mapping of the coastline of most of Arctic Canada being completed, expeditions to the area began to concentrate on scientific inquiry rather than geographical exploration. One of the first expeditions of this kind was led by Hayes aboard the United States in 1860. This expedition made soundings and ice observations in Baffin Bay and Smith Sound and measured temperatures at depth. Warm water of Atlantic character was found at subsurface levels in northern Baffin Bay.

In 1867, Petermann summarized the geophysical knowledge of the Baffin Bay region. He described a warm northerly current in eastern Baffin Bay, a cold south-flowing current in western Baffin Bay and cold water entering through Smith, Jones and Lancaster Sounds. The Nares expedition of 1875 made observations of temperature and chlorinity to depths of 210 m between the Arctic Ocean, Nares Strait and southern Baffin Bay. These observations allowed the identification of various water types based upon their temperature and salinity characteristics. A warm, saline Atlantic water layer was found below a layer of fresher colder Arctic water.

The period of purely oceanographic expeditions began in 1883 with the Swedish Sofia expedition, led by Nordenskiold (known for his Northeast Passage transit). Water samples were taken and temperatures measured to depths of several hundred meters with reversing thermometers. The West Greenland Current was described as having a cold low salinity upper layer, a warmer and more saline mid-depth layer and a deep layer, colder and slightly less saline than the middle layer.

Between 1884 and 1887, a Danish naval expedition aboard the Fylla greatly contributed to the oceanographic knowledge of the Davis Strait region. Hydrographic sections were occupied between Godthaab and Svartenhuk Peninsula at latitude 71°, as well as off the Baffin Island coast. The results of these expeditions established that a southward current flows down the Baffin Island coast into the Labrador Sea; a mixture of Atlantic and East Greenland polar water forms the West Greenland Current; and the West Greenland Current branches at the Davis Strait ridge, part turning to the west and part continuing north along the Greenland coast. Surface currents, deduced from ice-drift, were recorded in 1898-1899 on the Windward expedition in northern Baffin Bay.

In 1900, Petterson analyzed the existing data and described two currents flowing southward from Baffin Bay. The existence of one along the western shore from Smith Sound to Davis Strait has since been confirmed, but the other beginning near Cape York and merging with the first in Davis Strait has proven to be chimerical. The Tjalfe expedition of 1908-1909 provided data which implied that the deep waters of Baffin Bay originate in the Arctic Ocean, indicating a southward flow through Smith Sound and a net inflow through Jones and Lancaster Sounds.

The Titanic disaster occurred in April, 1912 and led to the establishment of the International Ice Patrol under the United States Coast Guard. Surveillance of icebergs in the shipping lanes was quickly expanded to include predictions of the severity of impending seasons. Knowledge of the Baffin Current, as well as the Labrador Current, became essential and stimulated further measurements in the Baffin Bay region.

The year 1928 proved to be of particular importance for physical oceanographic studies of the region with two major expeditions being launched. The first, the cruise of the Godthaab, had as its primary objective the study of the circulation of all Baffin Bay. With the measurement of vertical profiles of water temperature, salinity and other properties at 145 locations in Baffin Bay, the observations collected by this expedition remained for many years after, the most complete physical oceanographic data set for Baffin Bay. Sections which the Godthaab was unable to occupy because of heavy ice conditions off Baffin Island were taken by the U.S.C.G.S. Northland in 1940.

By the time of the Godthaab expedition, theoretical knowledge of ocean currents had developed to the point where currents could be deduced from the large scale distribution of water masses. By assuming a simple balance between the Coriolis force and pressure gradients, as deduced from profiles of water densities, so-called dynamic or geostrophic currents could be calculated. These currents were computed relative to an assumed "depth of no motion", normally taken just above the bottom. Though this method of determining ocean currents was indirect and subject to a number of uncertainties inherent in the necessary assumptions, in addition to possible measurement errors, it formed the basis for studies of oceanic circulation until the 1960's, when new technology enabled meaningful direct current measurements.

Because of the historical importance of the dynamic method, the derivation is presented in some detail. The average vertical velocity shear between two hydrographic stations is computed from the horizontal density gradients between the stations. The basis of such computation is the thermal wind equations, which are derived under the geostrophic assumptions:

(1) Frictionless flow;
(2) Steady-state flow;
(3) Initial terms are negligible;
(4) The pressure is hydrostatic.

The resulting equation is:

$$v\frac{\partial \rho}{\partial z} + \rho\frac{\partial v}{\partial z} = -\frac{g}{f}\frac{\partial \rho}{\partial x} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (1)$$

where v is the current velocity, the density, z the vertical coordinate positive up, g the acceleration of gravity, f the Coriolis parameter and x the horizontal coordinate positive to the right of the direction of flow.

The ratio of the first term to the second can be represented as:

$$\frac{\delta \rho}{\rho} \Big/ \frac{\delta v}{v} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (2)$$

or the ratio of the relative density change to the relative velocity change. This ratio is, virtually everywhere in the ocean, of the order of 10^{-2} or smaller. The first term can, therefore, be ignored, and the equation upon which the dynamic method is based becomes

$$\rho\frac{\partial v}{\partial z} = -\frac{g}{f}\frac{\partial \rho}{\partial x} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (3)$$

(3) implies that water with a lower density will generally be found to the right of a current in the northern hemisphere.

If this relation is valid, the vertical shear can be computed from water densities, and absolute currents computed by integrating v/ z in the vertical and selecting a proper reference level (constant of integration).

A dynamic analysis of the results of the Godthaab expedition was presented by Kiilerich (1939), and updated by Barnes (1941) to include the additional sections occupied by the Northland in 1940. The computed dynamic topography relative to a 1500 decibar "level of no motion" is shown in Figure 3-2, where the geostrophic flow is parallel to the contour lines and is inversely proportional to the spacing between the contour lines. The northward West Greenland current and southward Baffin current are clearly evident on the east and west sides of Baffin Bay, respectively. While the West Greenland current is generally weaker than the Baffin current, with typical speeds of 3 to 8 cm/s, the flow intensifies to the southwest of Cape York, reaching speeds of up to 23 cm/s. The Baffin Current flows roughly parallel to the length of Baffin Island with speeds of typically 20 cm/s in the centre or core of the current. Further upstream, there is evidence that a considerable portion of the Baffin Current intrudes into both Jones and Lancaster Sounds, although since the sections of stations are near the eastern extremities of the Sounds, it is not possible to determine the extent of these intrusions. In both Sounds, "the ingoing current hugs the north coast closely while the outgoing current on the whole takes up most of the section..." (Kiilerich, 1939); as a result there is a net eastward movement of water out of both Lancaster and Jones Sounds. Another significant feature in the circulation is a large cyclonic gyre in the central portion of northern Baffin Bay resulting from the northern flow on the east side, the southward flow on the west side, together with a weak easterly movement across the bay beginning well offshore of the entrance to Lancaster Sound. Finally, the results suggested that there is little difference in the motion throughout the water column below the upper 500 m. If one assumes that the deep water is stationary, this implies that there is little or no motion below 500 m.

In 1928, the first of a series of oceanographic cruises to Davis Strait and the Labrador Sea was made by the U.S. Coast Guard vessel Marion. From the observations of this cruise and subsequent cruises aboard the General Greene in 1931, 1934 and 1935 a detailed description emerged of the circulation in Davis Strait and the Labrador Sea, as presented in Smith, Soule and Mosby (1937).

With the advent of the Second World War, oceanographic activities in the area came to a halt. In the period following the war, physical oceanographic studies continued with the emphasis shifting to the channels of the Canadian Arctic Islands. This was not difficult to justify, since up to this time the oceanographic data collected in these channels had been extremely limited.

In 1954, oceanographic data was collected from H.M.C.S. Labrador on its epic voyage through the Northwest Passage. The results, presented by Bailey (1957) provide the first reasonably extensive set of data for Parry Channel. Distinct differences were found in water properties along the length of Parry Channel, with the waters of Baffin Bay and eastern Parry Channel being denser than the corresponding waters of the Beaufort Sea and western Parry Channel above 200 m depth. Below this level, the Arctic waters of the Beaufort Sea are denser and below 500 m, they are denser than any water found in Baffin Bay.

Further oceanographic surveys were carried out from the Labrador in 1956 and 1957. On the former cruise, most of the stations were located in Prince Regent Inlet, Gulf of Boothia, Foxe Basin and Hudson Strait; however, two sections were occupied in Lancaster Sound (Collin, 1958). The 1957 cruise was by far the most comprehensive study of Lancaster Sound to that time with five cross-sections of oceanographic stations completed in the Sound (Collin, 1962).

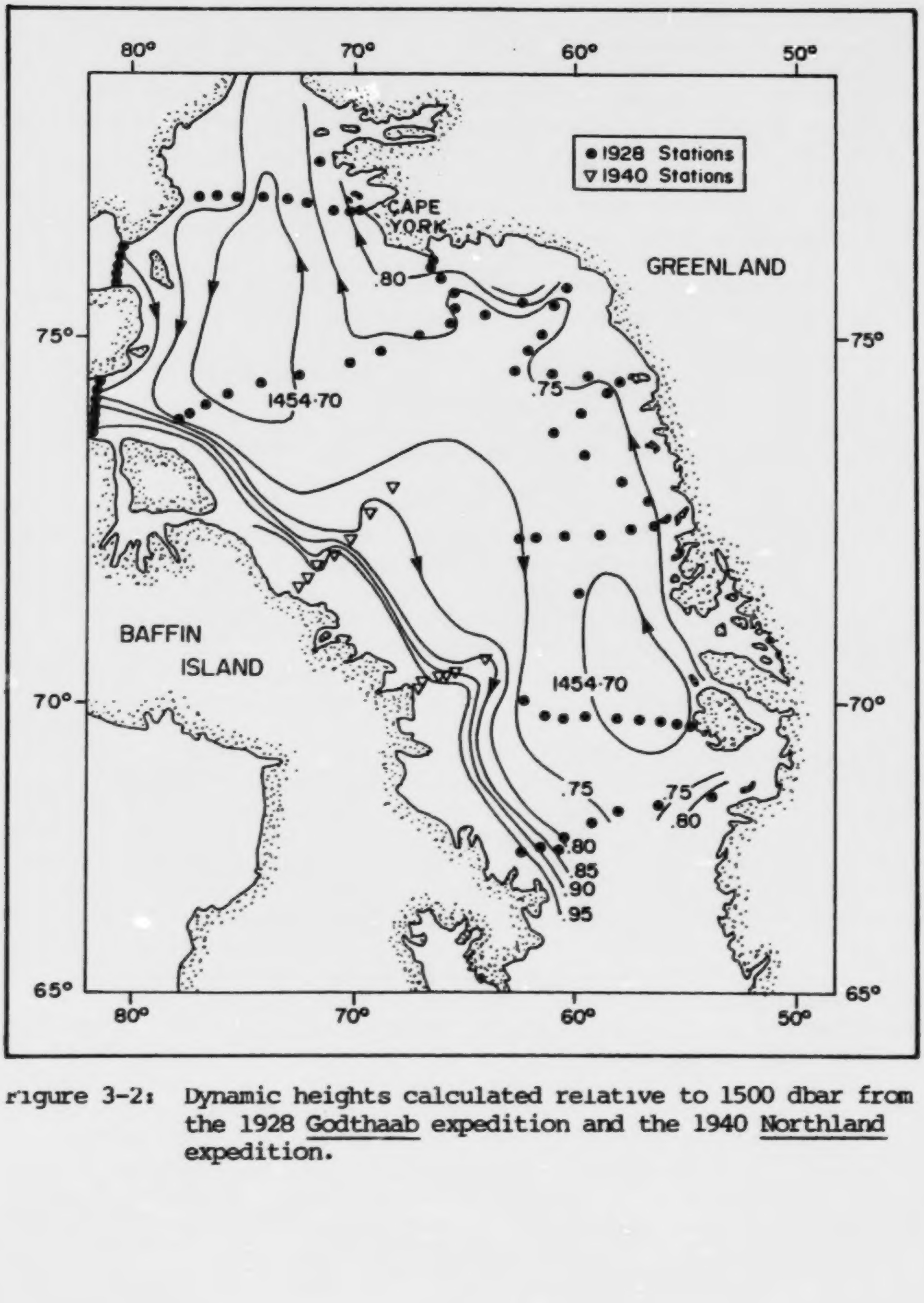

80°
70°
60°
50°
75°
70°
65°
● 1928 Stations
▽ 1940 Stations
CAPE YORK
GREENLAND
BAFFIN ISLAND
.80
.75
1454·70
1454·70
.75
.75
.80
.80
.85
.90
.95

Figure 3-2: Dynamic heights calculated relative to 1500 dbar from the 1928 Godthaab expedition and the 1940 Northland expedition.

In 1960, another oceanographic survey of Lancaster Sound was carried out, involving two research vessels. The M.V. Theta occupied three sections of oceanographic stations in the eastern half of Lancaster Sound, one of which was occupied twice, over a period of one month. As well, the C.C.G.S. Labrador occupied two sections in Lancaster Sound in that same year. Unfortunately, analysis of this valuable data set was neglected for many years. Recently, Barber (1978) has carried out a preliminary data analysis; a final report will be available soon.

Over the period from 1954 to 1970, several other oceanographic cruises to Baffin Bay and adjoining water bodies were completed. While the number of stations occupied and the station locations varied considerably among the cruises, they did have the following common features:

(1) the cruises were carried out from Canadian or United States Coast Guard vessels.

(2) much of the collected data has never been published.

(3) in most cruises, the ships had other responsibilities in addition to the oceanographic studies (e.g., ice-breaking support for shipping, other scientific programs). As a result, the data is not as synoptic in coverage as might be hoped. A listing of these cruises are presented in Table 3-1, together with references to published analyses of the data, where available.

As part of an excellent review of the physical oceanography of Northern Baffin Bay and its importance to the Northern polynya, Muench (1971) analyzed oceanographic data from many of the cruises to the area between 1916 and 1966. His summary of the physical oceanography of Baffin Bay, based on data collected between 1916 and 1966, remains valid to this time, therefore we present rather lengthy but relevant excerpts from Muench's summary:

The waters of Baffin Bay may be divided, on the basis of their vertical temperature distribution, into three layers. The characteristics of this structure have remained unchanged from 1928 to 1966. The layers are:

(a) an upper layer of relatively cold (0°C to -1.8°C), low salinity ($<$ 30°/oo to about 34.4°/oo) Arctic water. This extends from the surface down to 100-150 m in northeastern Baffin Bay, to 200-300 m in northwestern Baffin Bay and Lancaster Sound, and to the bottom in Smith and Jones Sounds. Minimum temperatures in a prominent cold core occur in northeastern and north-central Baffin Bay; the core is a consequence of winter thermohaline convection within Baffin Bay. A shallower and less pronounced core in northwestern Baffin Bay, and Smith, Jones and Lancaster Sounds is a remnant of the winter convective layer in the Arctic Ocean.

Arctic water is water of Atlantic Ocean origin which either entered Baffin Bay via Davis Strait and was modified by cooling and admixture of runoff within northern Baffin Bay, or was modified by cooling and freshening within the Arctic Ocean prior to entering Baffin Bay from the north.

(b) An intermediate layer of warmer (0°C to >2°C), more saline (34.2°/oo to 34.5°/oo) Atlantic water. This extends from the bottom of the Arctic water layer down to 1200-1300 m in northern Baffin Bay proper, down to 600-700 m in Lancaster Sound, and is absent from Smith and Jones Sounds. Maximum temperatures occur within a pronounced warm core in this layer.

The Atlantic water originates from the Atlantic Ocean via Davis Strait, from whence it is advected northward by the West Greenland Current while losing heat due to mixing with Arctic water. Relatively shallow sill depths between Baffin Bay and the Arctic Ocean prevent a southward flow of Arctic Ocean Atlantic water.

(c) A deep layer of relatively cold (0°C to -0.4°C) Deep Water, including water below 1800 m of extremely uniform temperature (-0.40°C) and salinity (34.48°/oo) - the Bottom Water. The Deep Water is characterized by a temperature decrease and nearly uniform salinity as the depth increases to 1800 m. Horizontal temperature and salinity variations, if any, are undetectable.

The Deep Water is identical to water occurring at 200-250 m depth in the Eurasian Basin of the Arctic Ocean. Water of proper type to contribute to Deep Water only above about 1400 m depth occurs commonly in Nares Strait, however. Deep Water below 1400 m, including Bottom Water, is suspected to originate from the Arctic Ocean as irregular pulses; however, these have never been observed. It is improbable that winter thermohaline-convection within Baffin Bay contributes to the Deep Water...

Table 3-1

A summary of oceanographic expeditions in Baffin Bay, Lancaster Sound and Jones Sound, 1928-1970.

Year	Vessel	Number of Sections in			Publication Reference
		Baffin Bay	Lancaster Sound	Jones Sound	
1928	Godthaab	11	1	1	Riis-Carstensen (1936)
1940	Northland	2	—	—	Barnes (1941)
1954	Labrador	1	2	2	Bailey (1957)
1956	Atka	(a)	—	—	—
1956	Labrador	—	2	—	Collin (1958)
1957	Labrador	(b)	5	—	Collin (1962)
1958	Atka	(a)	—	—	—
1959	Westwind	(a)	—	—	NODC
1960	Labrador	6	2	—	Barber (1978)
1960	Theta	—	3	—	Barber (1978)
1960	Westwind	(a)	—	—	Barber (1978)
1961	Labrador	7	4	—	Barber & Huyer (1971)
1961	Edisto	(a)	—	—	NODC
1962	John A. McDonald	—	1	1	Barber & Huyer (1971)
1962	Labrador	5	3	3	Barber & Huyer (1971)
1962	Atka	(a)	—	—	Barber & Huyer (1971)
1962	USSR vessel	(f)	—	—	MEDS
1963	Evergreen	3	—	—	Franceshetti et al. (1964)
1963	Labrador	5	—	5	MEDS
1964	Labrador	6	—	—	MEDS
1965	Labrador	3(d)	—	—	MEDS
1966	Edisto	6	1	1	Palfrey & Day (1968)
1967	Edisto	(c)	—	—	Barber (1978)
1968	Westwind	(e)	—	—	Muench (1971b)
1968	Labrador	—	1	—	Herlinveaux (1970)
1969	Southwind	(g)	—	—	Moynihan and Muench (1971)
1969	Westwind	(h)	—	—	Moynihan and Muench (1971)
1970	Westwind	6	1	1	MEDS

(a) 17 stations through Baffin Bay.
(b) 15 stations through Baffin Bay.
(c) 26 stations throughout Baffin Bay.
(d) in addition to the three sections occupied off Cape Dyer, 9 additional stations were occupied through Baffin Bay.
(e) 6 major sections across S. Baffin Bay and N. Davis Strait.
(f) 4 sections from Greenland coast to mid-channel in S. Baffin Bay and N. Davis Strait.
(g) detailed grid of 35 stations in Melville Bay.
(h) detailed grid of 15 sections in Melville Bay-Thule area.
NODC - data on file at National Oceanographic Data Center, U.S.A.
MEDS - data on file at Marine Environment Data Service, Ottawa, Ontario, Canada.

> The baroclinic flow pattern within northern Baffin Bay consists of the northward West Greenland Current in its eastern part, the southward Baffin Current in its western part, and a cyclonic gyre east of Devon Island. Cyclonic circulation of Baffin Bay water occurs in southern Smith Sound and in eastern Jones and Lancaster Sounds. The West Greenland Current transport northward only about 10% of the volume transported southward by the Baffin Current, and is not always present during the late summer.
>
> The cyclonic circulation within northern Baffin Bay is driven by a combination of winds and baroclinic fields resulting from low-salinity, nearshore wedges due to meltwater admixture. Both the baroclinic field, due to the presence of less dense Arctic Ocean water, and westward itensification processes appear to be important in the dynamics of the Baffin Current.
>
> Bottom topography exerts some control on the currents in Lancaster Sound and off Cape York. This control, coupled with the temperature distribution in the Atlantic water, suggests that the currents extend nearly to the bottom there. Year-to-year variations, including formation of eddies and gyres, may also occur in Lancaster Sound and off Cape York...
>
> While overall summer conditions have remained constant, the northern Baffin Bay region is characterized by a high degree of time variability in its circulation and hydrographic structure details. It is, therefore, possible at this time to depict these features on only a gross scale...."

3.4 Scientific Investigations, 1971-1979

By 1970, the frequency of oceanographic cruises to the area had markedly declined. With the relatively large number of oceanographic cruises of a reconnaissance nature that had been carried out over this large area for the past fifteen years, there was little scientific impetus to continue them. This tendency was first discernible in the latter half of the 1960's when studies had begun to concentrate measurements in a particular subregion; for example, the U.S. studies of 1969 with closely spaced stations located in the Melville Bay-Cape York area.

In spite of the decline of oceanographic activities, many major deficiencies remained in the understanding of the physical oceanography of the area. One such deficiency was the lack of direct measurements of the circulation. Up to that time oceanographers inferred water movements from an assumed balance between the internal pressure gradient and the Coriolis force. Questions of the validity of the necessary assumptions greatly limited the accuracy of existing quantitative descriptions of the oceanic circulation.

By the late 1960's, advances in miniaturized electronics had resulted in vastly improved oceanographic instrumentation, capable of making meaningful direct measurements of currents. The two most notable developments were the self-recording current meter which could be left "in-situ" to obtain measurements of currents from one location over long periods of time and the satellite-tracked drifting buoy which drifted with the currents and reported its position through a satellite system.

The first long-term moored current meter measurements in Baffin Bay were made in Smith Sound in 1963 (Franceschetti et al, 1964; Day, 1968; Coachman and Augaard, 1974). Current meters were moored at 150 and 350m depths and, along with dynamic calculations, indicated a surface flow to the north on the east side of the Sound, and to the south on the west side. The flow at depth was to the north at mid-channel but to the south on either side. In 1968 further current meter measurements were made (Avis and Coachman, 1971) at two sites in the entrance to eastern Smith Sound, approximately 110 km northwest of Thule. The 11 days of measurements indicated the importance of the semi-diurnal tidal currents; the amplitude of the semidiurnal variations of approximately 10 cm/s being an order of magnitude greater than the amplitude of the diurnal tidal currents. The average flow at both sites was northwesterly, in agreement with the expected cyclonic circulation pattern of northern Baffin Bay. Unfortunately, because of the short record length, longer period variations in the flow were not adequately resolved.

In 1974, the Canadian Hydrographic Service installed and recovered a moored subsurface current meter at 85 m depth, 3.0 km off Cape Crauford in Lancaster Sound (see Figure 3-3). The 27 day record of currents obtained at this location was the first current meter time series for Lancaster Sound. The net flow set southeasterly into Admiralty Inlet at 5.2 cm/s (Fissel and Wilton, 1978). The tidal currents account for over 50% of the total variance of the current time series with the M_2 constituent having the largest amplitude of 20 cm/s. In view of the alignment of the tidal currents with the north-south bathymetry for the four major tidal constituents, the nearshore location clearly had an important influence on the currents observed. As a result, offshore currents could differ markedly from these measurements.

Subsurface current meter moorings in deeper offshore locations were placed in eastern Lancaster Sound in 1970 and 1976. In 1970, two moorings were installed on the northern and southern sides of eastern Lancaster Sound (Muench, 1970); neither were recovered. In 1976, a deep water subsurface mooring supporting four current meters was deployed at 75° 3.5'N 81° 17.5'W in the centre of eastern Lancaster Sound by Oceanographic Services Inc. for Norlands Petroleum Ltd. Unfortunately, after being in place for a month, the mooring could not be located. In the autumn of 1978, two of the current meters together with the buoy which provided floatation were found by local hunters near Clyde, N.W.T., approximately 500 km southeast of the deployment site. These instruments recently arrived at the Institute of Ocean Sciences, Department of Fisheries and Oceans; the data tapes are being translated and checked for any valid data.

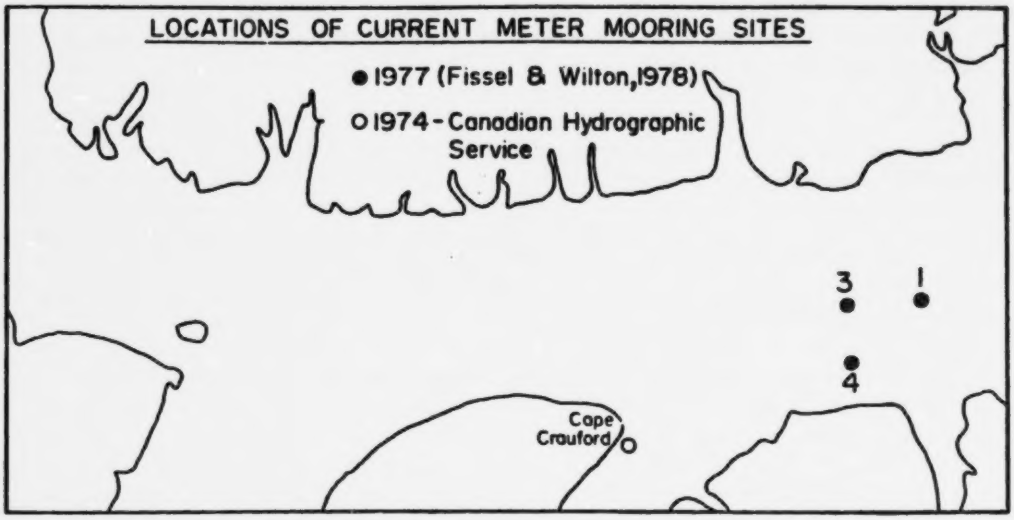

LOCATIONS OF CURRENT METER MOORING SITES
● 1977 (Fissel & Wilton,1978)
○ 1974 - Canadian Hydrographic Service
3
1
4
Cape Crauford

Figure 3-3: Locations of Current meter moorings operated in Lancaster Sound in 1974 and 1977.

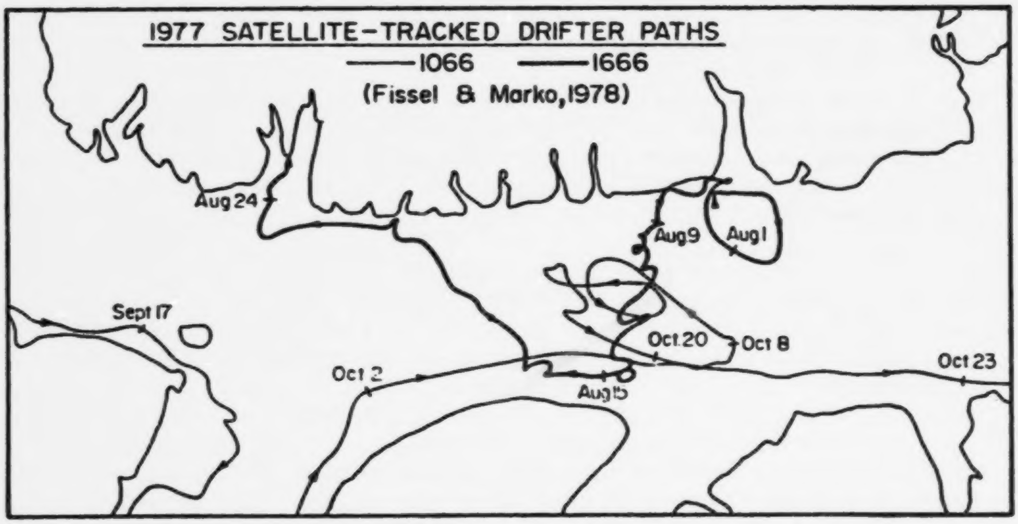

1977 SATELLITE-TRACKED DRIFTER PATHS
1066
1666
(Fissel & Marko,1978)
Aug 24
Aug9
Aug1
Sept 17
Oct.20
Oct 8
Oct 2
Aug15
Oct 23

Figure 3-4: Paths of satellite-drifters deployed in the summer of 1977 (Fissel and Marko, 1978).

In 1977, Arctic Sciences Ltd., sponsored jointly by the Institute of Ocean Sciences and Norlands Petroleum. deployed four subsurface current meter moorings in eastern Lancaster Sound. After nearly two months of operation, three of the moorings (see Figure 3-3) were recovered. The results were summarized by Fissel and Wilton (1978):

"The mean circulation is characterized by strong southerly flows in the centre of the Sound and easterly flows along the southern side at the near surface and 200 m levels; this circulation pattern is consistent with the existence of an anti-clockwise gyre extending into eastern Lancaster Sound from northwestern Baffin Bay as described by Muench (1971) and others. In the centre of the Sound, the near-surface currents can reach speeds of up to 112 cm/s with an average magnitude of 30 cm/s. Based on wind measurements taken at a shore station on the south coast, surface movements expected from the large scale circulation pattern were generally larger than those movements expected from directly generated wind driven currents.

The temporal variations of the currents at all depths vary over relatively long periods; the power spectra of the currents showed that the largest spectral levels occurred in the lowest frequency band centred on a frequency of 0.052 cycles per day or a period of 19 days. For the north-south component of the current at the near surface and 200 m levels of the two stations located in the centre of the Sound, the low frequency variations were particularly important with the lowest frequency spectral band accounting for 62 to 84% of the total variance.

The southerly current measured in the centre of the Sound is baroclinic in nature; the low frequency variations, though significantly correlated, are reduced in amplitude by a factor of about 2 at the 200 m level in comparison with the near surface variations.

The near surface north-south component variations at the two centre stations, separated by 30 km, are essentially opposite in phase. This is interpreted as evidence of a shift in the extent of the intrusion of the anti-clockwise gyre within eastern Lancaster Sound.

Tidal currents are generally small in comparison with the low frequency currents at the near surface and 200 m levels. From a harmonic analysis of the current data, the diurnal and semi-diurnal tidal ellipses are found to be oriented along the east-west axis of the sound with typical amplitudes of 7 to 10 cm/s. At the 550 m level, the tidal currents are relatively more important, accounting for roughly one-half of the total variance, largely because the lower frequency variations are significantly reduced at this depth."

In the same year, Arctic Sciences Ltd., on contract to the Institute of Ocean Sciences, used 10 satellite-tracked drogued buoys to measure near-surface currents primarily in Barrow Strait, west of Lancaster Sound. Five of these drifters moved eastward out of Barrow Strait and into Prince Regent Inlet, revealing a strong (50 cm/s) and persistent southeasterly flow into Prince Regent Inlet. Two travelled through Lancaster Sound, providing data on near-surface currents along their track (see Figure 3-4). Of particular interest were the eddy-like structures revealed from the buoy tracks in the centre of Lancaster Sound off Brodeur Peninsula and Admiralty Inlet. These eddies had scale sizes of 30 to 60 km and were variable as to location and the sense of rotation. One buoy was carried into Baffin Bay by the strong easterly current on the south side of eastern Lancaster Sound with easterly movements of 50-60 cm/s off Borden Peninsula and Bylot Island.

The combined results from these 1977 studies suggested that the current intruding into eastern Lancaster Sound from Baffin Bay (previously described as an anti-clockwise gyre) is the dominant feature of the circulation in the area. These first direct measurements indicated that speeds in the core of the spatially varying current commonly reach 50 cm/s or more. These speeds are considerably larger than the values computed indirectly on the basis of the oceanographic temperature and salinity profiles, which had provided the basis for investigations of the circulation prior to the 1977 studies.

In the central part of Lancaster Sound, west of the intrusive current, the circulation appeared to be characterized by relatively weak flows often occurring in the form of variable and irregular large scale eddies. Stronger and more persistent flows can occur along the southern side of the Sound; these flows appear to result from intrusive currents (analogous to the one in eastern Lancaster Sound) associated with the net eastward transport through the Sound and extending into Prince Regent Inlet (Fissel and Marko, 1978) and possibly Admiralty Inlet.

4. PHYSICAL OCEANOGRAPHY FIELD PROGRAMS - 1978 AND 1979

Due to the limitations of the existing physical oceanographic data base discussed above, an extensive measurement program was carried out in the summer of 1978 and repeated in a somewhat expanded and modified form in the summer of 1979. As well, limited amounts of data were collected through the autumn, winter and spring months of 1978-79.

The second summer of field work proved valuable in effectively studying the oceanography of the area. It presented the opportunity to probe the permanence of important summer circulation features. As well, with the rather limited coverage of historical data, the much more detailed information obtained in 1978 provided the basis for designing an improved field program for the summer of 1979.

The physical oceanographic field work can be divided into several components:

1. subsurface current measurements from moored current meters
2. satellite-tracked drogued drifter measurementes of near-surface currents
3. extensive measurements of profiles of conductivity, temperature and depth (CTD) data
4. shipboard vertical profiles of currents over the upper 50 m of the water column
5. water level measurements collected with a bottom-mounted water-level gauge
6. measurements of surface currents and vertical CTD profiled in nearshore zones.

The data coverage and measurement accuracies are described below. More detailed information can be obtained from data reports issued for each program component, as listed in the Appendix.

4.1 Subsurface Current Data

Time series measurements of subsurface currents were obtained at 14 locations in the summer of 1978 (July 31-Oct. 5) and 18 locations in the summer of 1979 (July 23-Oct. 2) as shown in Figures 4-1 and 4-2. As well, five moorings were recovered at the beginning of the summer 1979 studies which had been in place since the end of the summer 1978 program. At these winter locations (stations 1, 2, 8a, 10 and 13), the currents were sampled at hourly intervals while the sampling interval for the summer current meter measurements was 10 minutes.

The current meters were placed at standard depths of 35 m, 125 m, 250 m, 500 m and 750 m with each mooring containing a meter at 35 m depth. The depths of the other meters varied according to location, with every mooring having from two to five current meters, as indicated in Figure 4-3.

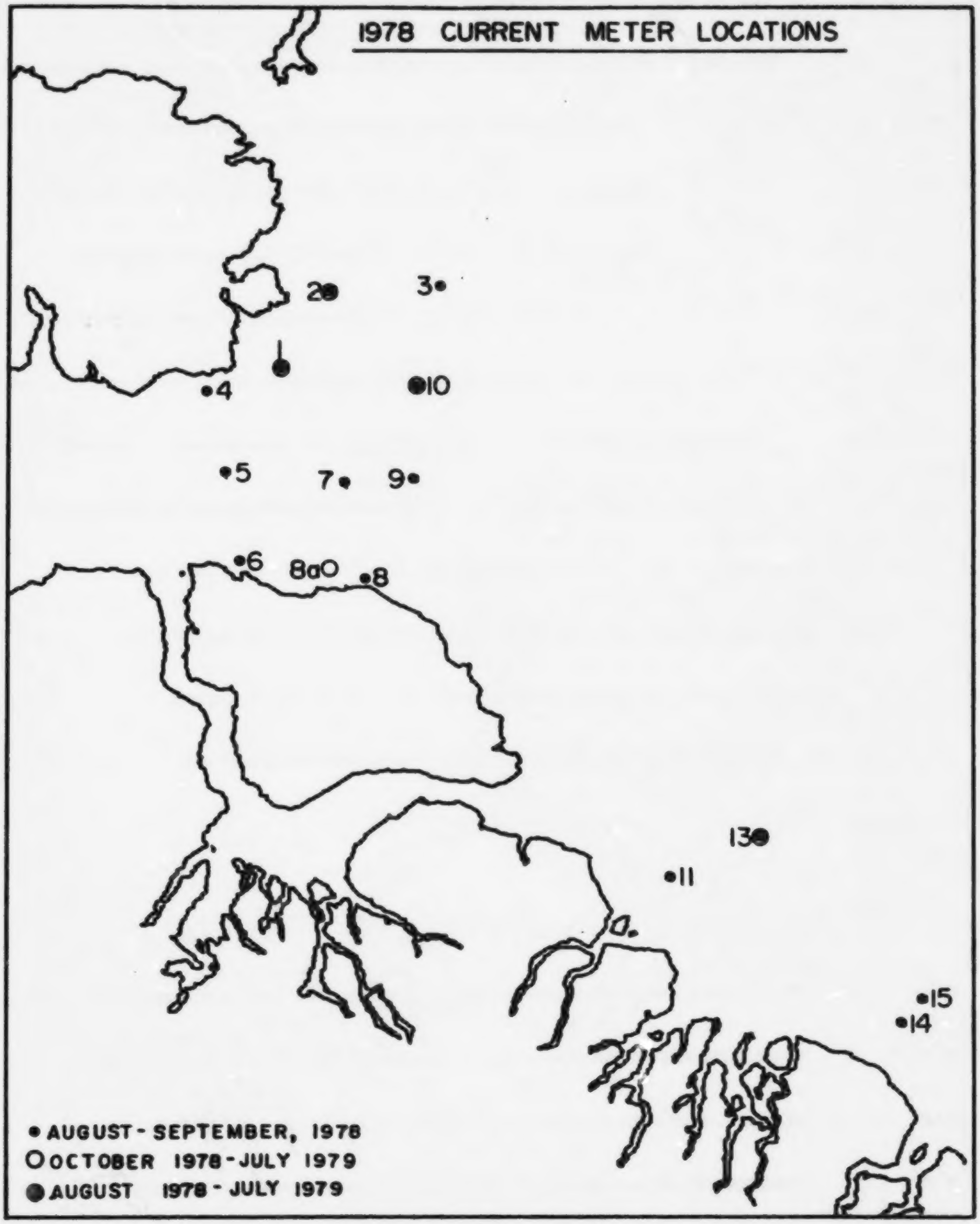

1978 CURRENT METER LOCATIONS
2
3
1
4
10
5
7
9
6
8a
8
13
11
15
14
● AUGUST - SEPTEMBER, 1978
○ OCTOBER 1978 - JULY 1979
● AUGUST 1978 - JULY 1979

Figure 4-1: Locations of summer 1978 current meter moorings. Stations marked with a (O) were operating from Oct. 1978 to July 1979 and subsequently recovered.

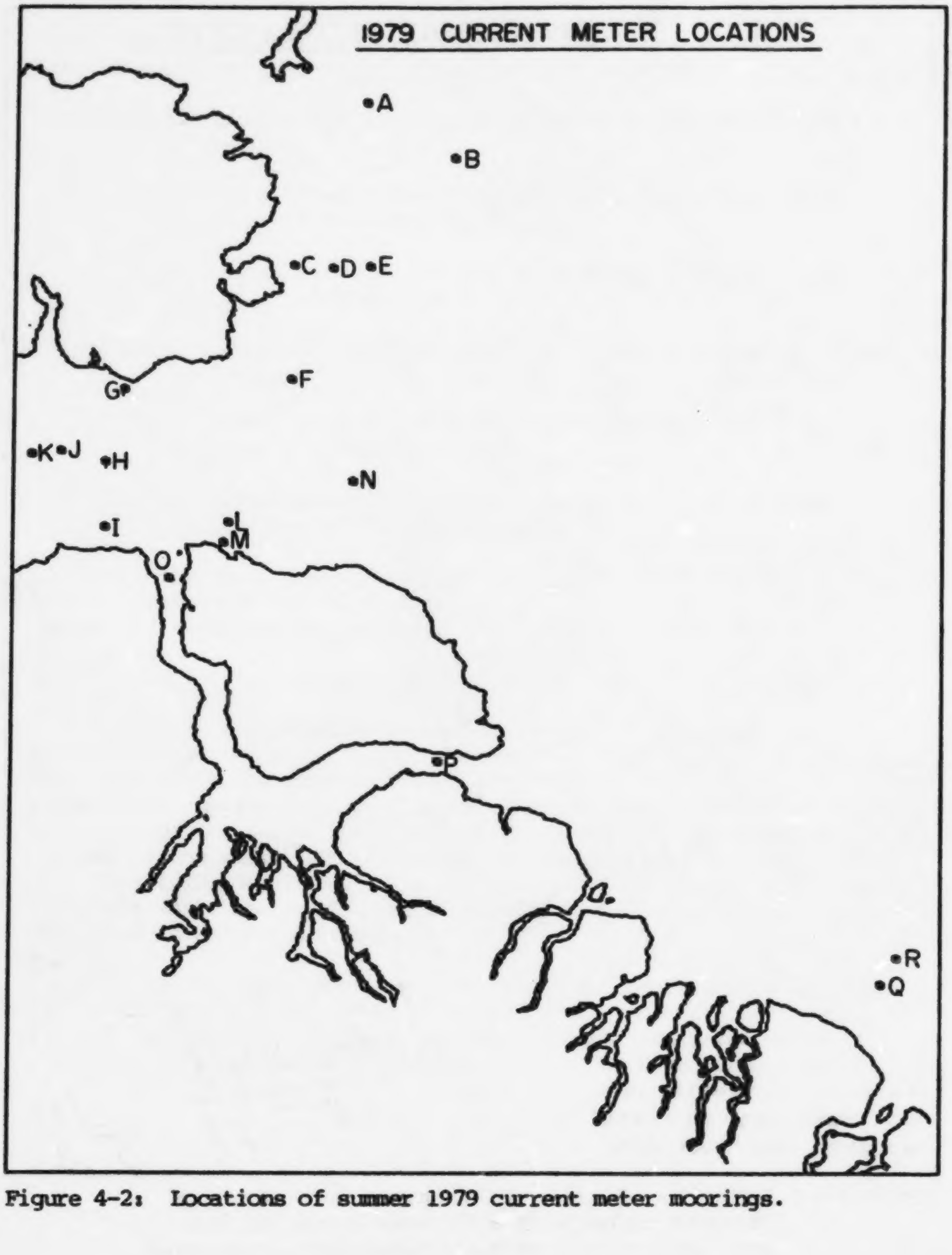

1979 CURRENT METER LOCATIONS
A
B
C
D
E
F
G
K
J
H
N
I
L
M
O
P
R
Q

Figure 4-2: Locations of summer 1979 current meter moorings.

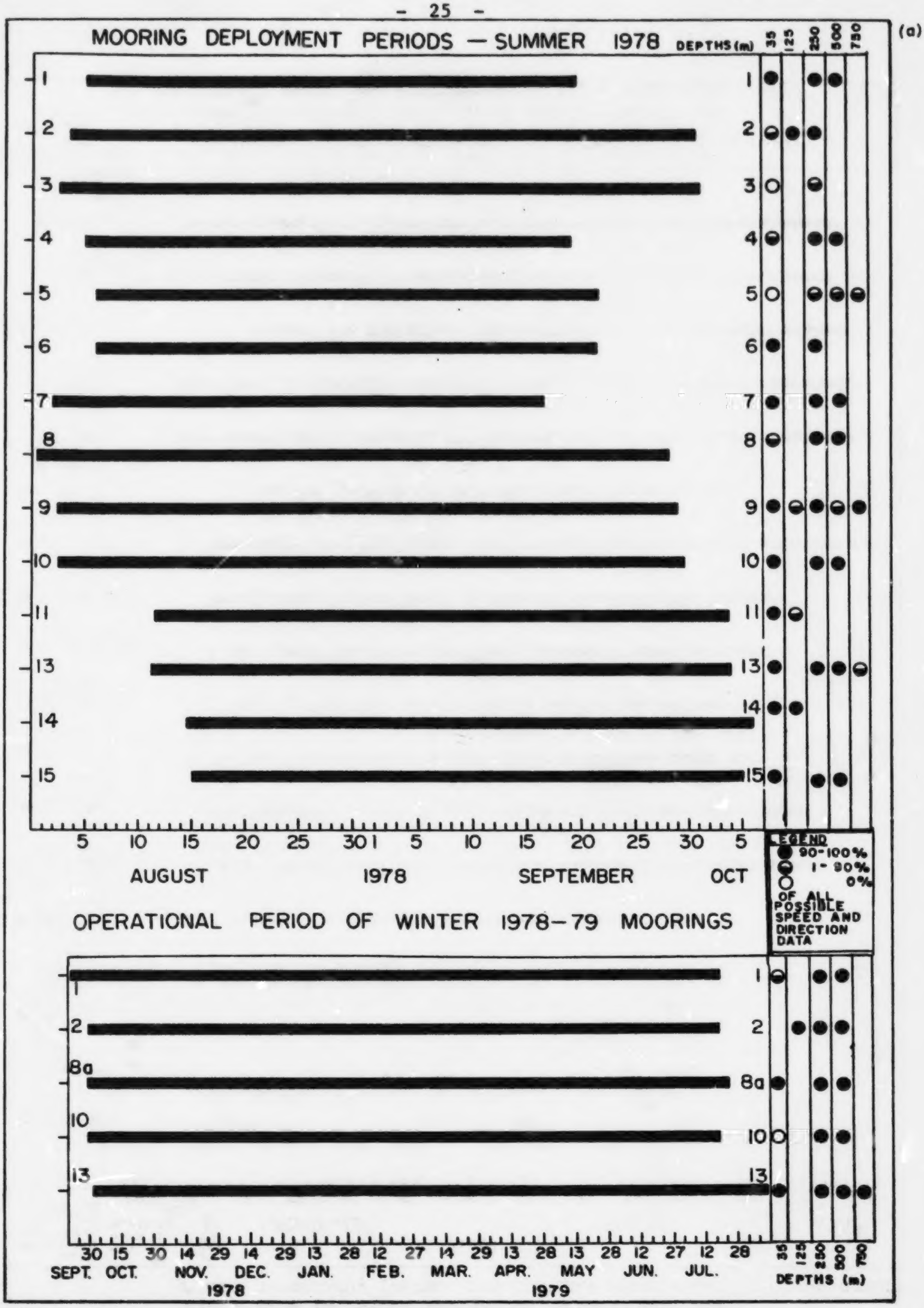


Figure 4-3(a): Operational periods and nominal instrument depths for each current meter mooring in (a) summer 1978, winter 1978 - 1979.

(b)

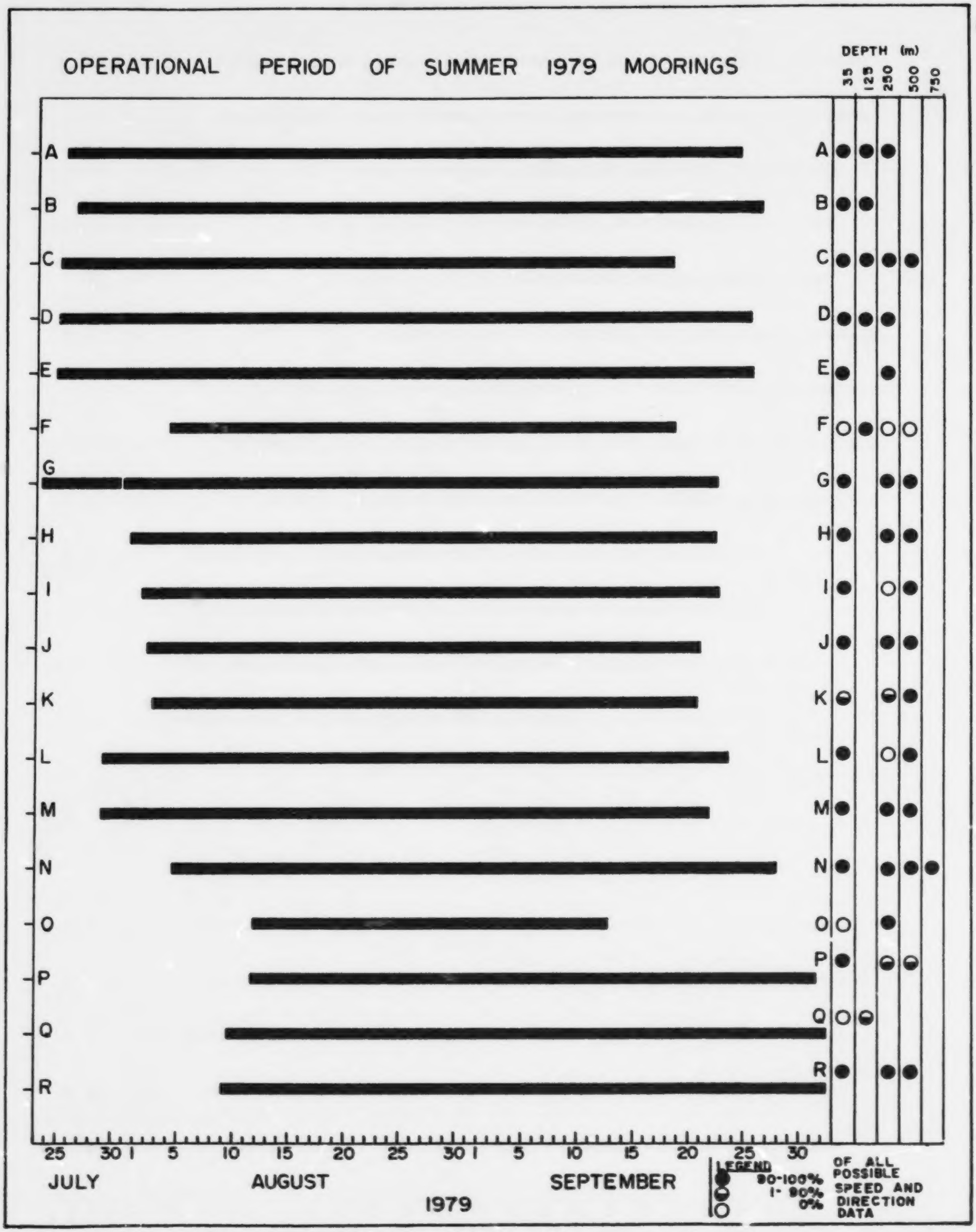


Figure 4-3(b): Operational periods and nominal instrument depths for each current meter mooring in (b) summer 1979.

The current meters were all Aanderaa RCM-4 models modified to provide improved directional sensitivity and to operate over 10-month periods. The current meters measure temperature, conductivity and pressure as well as speed and direction with accuracies as listed in Table 4-1.

Table 4-1

Quantity	Accuracy
Speed	± 1 cm/s or ± 2% of the actual speed, whichever is greater
Direction	from ± 5 degrees to ± 18 degrees, according to location and mooring design
Temperature	± 0.15°C
Conductivity	resolution of 0.1% of range, either 70 mmho/cm or 42 mmho/cm. Accuracy unknown.
Pressure	± 1% of range which varies from 345 dbar to 2070 dbar.

The accuracies cited above are supplied by the manufacturer with the exception of that of the directional channel. Directional accuracies are lower in this area due to proximity of the north magnetic pole. However, with modifications to the current meter and mooring design and careful calibration procedures, directional errors can be reduced. The actual directional error varies according to the local horizontal field strength, calibration history of the meter and mooring design. Fissel and Wilton (1980) estimate that the directional accuracies range from ± 5 degrees to ± 18 degrees for this study.

4.2 Satellite-Tracked Drifter Data

A total of fifteen (15) satellite-tracked drifters were released in the summer of 1978 followed by thirty-five (35) drifters released in the following summer. The drifters, manufactured by Hermes Electronics Ltd., consist of a buoy with a large sail-type drogue attached beneath; with the drogue at depths from 4.6 to 11 m, accounting for over 90% of the drifters' total surface area, the drifters are expected to move with the currents present at these depths.

The drifters were located by means of satellite positioning systems: In 1978, the RAMS system (Coates, 1973) was used while, by 1979, the more accurate ARGOS system (Bessis, 1979) had become available and was employed for this purpose. The positional accuracy of the RAMS system is ± 4.6 km at the 95% confidence level, while the corresponding accuracy for the ARGOS system is ± 1.2 km (Fissel, 1980). For calculation of the velocity, a minimum time interval of 0.5 days was necessary for the 1978 drifters to achieve an accuracy of ± 15 cm/s. Due to the improved positional accuracy for the 1979 drifters, a velocity accuracy of ± 8 cm/s was achieved with a minimum time interval of 0.25 days.

The sampling rate of positional data varied considerably from 1978 to 1979. In August 1978, 4 to 5 valid positions were received per day for each drifter. However, after August, only 2 valid positions per day were obtained and periods of up to 2 days with no positions received were experienced. The 1979 drifters equipped with ARGOS transmitters had much higher sampling rates with an average of ten valid positions per day.

The deployment locations of the 1978 and 1979 drifters are presented in Figure 4.4. The first six drifters were deployed from Aug. 3 to Aug. 8 off the southeast coast of Devon Island. On Aug. 28, another five drifters were released to the east of Devon Island followed on Sept. 7 and 20 by the deployment of pairs of drifters on either side of Lancaster Sound.

Thirty-five drifters were released in the summer of 1979. Of these, eighteen were released off the east coast of Devon Island in three batches: On Aug. 12-13, Aug. 31 and Sept. 14-15. Fourteen drifters were released in central and western Lancaster Sound, with six being deployed on August 23-24, three being deployed on Sept. 5-6 and five being deployed on Sept. 13. The remaining three drifters were released off the north-east coast of Bylot Island on Aug. 15.

The operational periods varied considerably among the drifters ranging from 0 to 96 days. Operations were terminated due to the complete failure of many drifters, apparently due to ice or shoreline impact, or due to containment by the winter sea-ice. In 1978, the median operational period was only 11 days as compared to 28 days in 1979, probably a result of the more severe ice conditions of the earlier year.

Of the 1978 drifters, two survived the winter of 1978-1979 and one continued to operate throughtout the summer of 1979. Several of the drifters released in the summer of 1979 remained operational in 1980; however, the results obtained in 1980 are not included in this report.

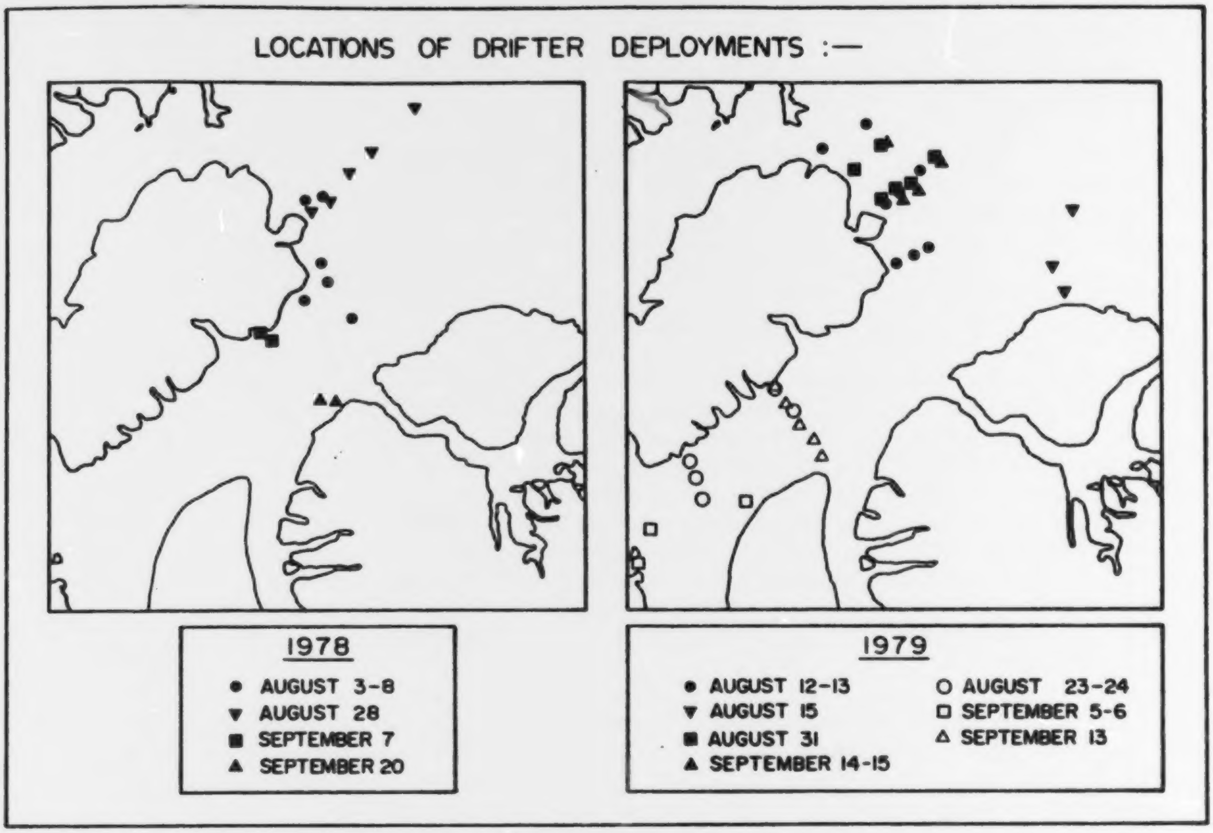

LOCATIONS OF DRIFTER DEPLOYMENTS :—
1978
● AUGUST 3-8
▼ AUGUST 28
■ SEPTEMBER 7
▲ SEPTEMBER 20
1979
● AUGUST 12-13
▼ AUGUST 15
■ AUGUST 31
▲ SEPTEMBER 14-15
○ AUGUST 23-24
□ SEPTEMBER 5-6
△ SEPTEMBER 13

Figure 4-4: Times and positions of deployments of 1978 and 1979 satellite-tracked drifters.

4.3 CTD Measurements

The CTD data is used to study the circulation of the area as well as to define the distribution of water properties: primarily temperature, salinity and density. Currents can be computed from CTD data by determining the internal distribution of density and assuming that the circulation is geostrophically balanced. This method formed the basis of much of the historical oceanographic results; however, the 1978 and 1979 studies have the advantage of providing simultaneous direct and geostrophically computed current measurements.

A Guildline Model 8706 digital CTD probe and Model 87102 control unit were used. The accuracies of the instrumentation as specified by the manufacturer are ± 0.005 parts per thousands equivalent salinity, ± 0.005°C in temperature and ± 2.25 dbar or ± 3.75 dbar according to the pressure sensor range. Sampling occurs at a rate of 25 samples per second which translates to a spatial sampling interval of 6 cm when lowered at 1.5 m/s.

The instrument was calibrated at the Northwest Regional Calibration Center, Bellevue, Washington before and after each cruise. In addition, independent measurements of salinity and temperature were collected with a water bottle mounted above the instrument. For the 1978 CTD data, the instrument performed well and there was good agreement between the bottle and CTD data. However, the 1979 CTD data is more erratic in salinity measurements due to an instrument malfunction. The general accuracy of the salinities is estimated as ± 0.02 parts per thousand for casts where bottle samples are available and ± 0.04 parts per thousand otherwise (Lemon, 1980).

A total of 193 CTD casts were taken at 85 stations between July 23, 1978 and October 8, 1978. The station locations are shown in Figure 4-5. In 1979, a total of 328 casts at 144 stations were made between July 17, 1979 and October 12, 1979 (Figure 4-6). The larger number of stations in 1979 is due to more detailed sampling in eastern Lancaster Sound and off Devon and Bylot Islands as warranted from an examination of the 1978 results. As well, the study area was extended further west into Lancaster Sound and to the north in and off the entrances to Jones Sound.

4.4 Current Profile Measurements

Using an Endeco Model 110 current meter, vertical profiles of currents were obtained from the vessel used for the oceanographic studies, M.V. Theron. According to the manufacturer's specifications, the speeds are accurate to ± 8 cm/s. The directional data was limited to accuracies of ± 30 degrees in weak horizontal magnetic fields as determined from both "in-situ" tests and laboratory tests (Fissel and Birch, 1980). These accuracies

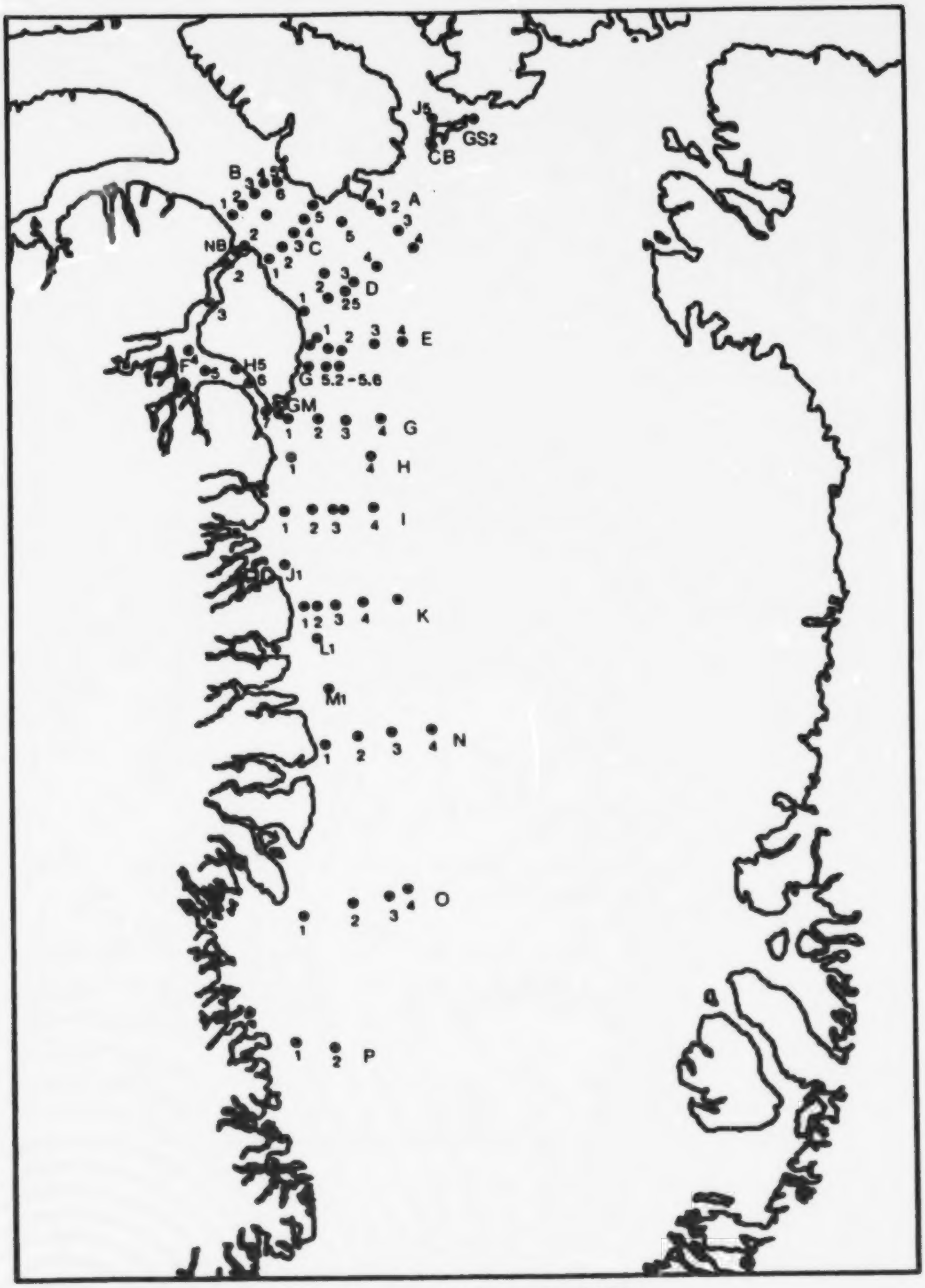

J5
GS2
CB
B 1 2 3 4 5 6
A 1 2 3 4
NB 2
C 1 2 3 4 5
2
D 1 2 3 4 5
3
E 1 2 3 4
F4
5
H5
6
G 5.2 - 5.6
GM
G 1 2 3 4
H 1 4
I 1 2 3 4
J1
K 1 2 3 4
L1
M1
N 1 2 3 4
O 1 2 3 4
P 1 2

Figure 4-5: Locations of CTD stations in 1978.

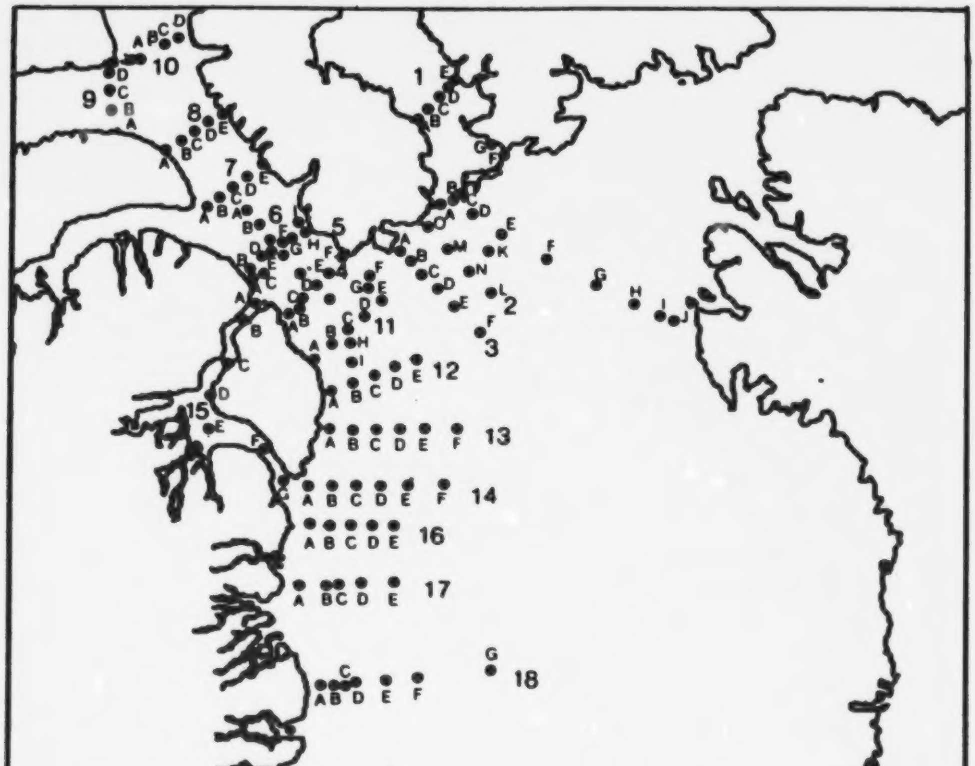

1
2
3
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
A B C D E F
A B C D E F
A B C D E
A BC D E
A B C D E F G
A BC D E
A BC E G
A B C D E
A BC D E
A B C D E F G

Figure 4-6: Locations of CTD stations in 1979.

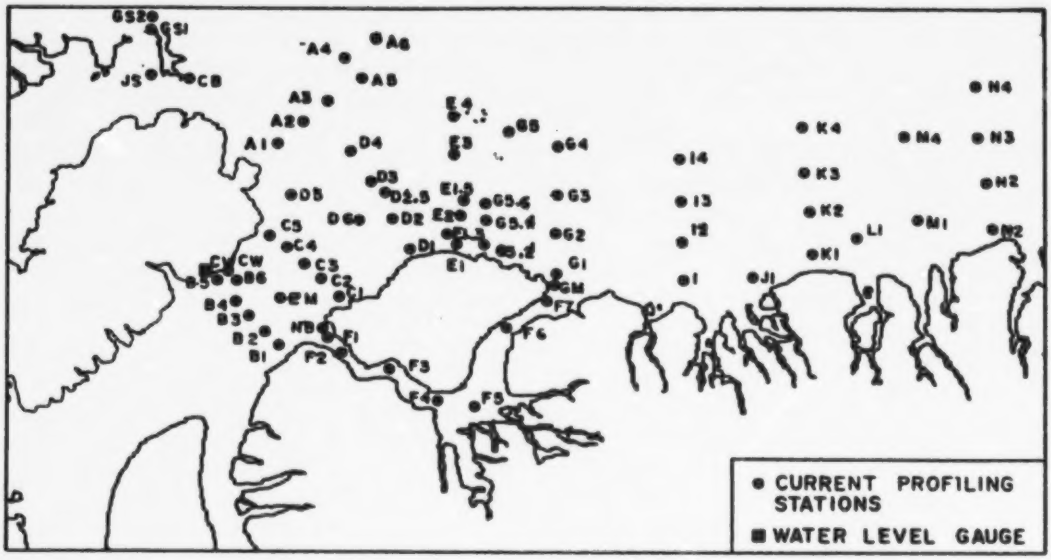

GS2
GS1
JS
CB
A4
A6
A5
A3
A2
A1
E4
G6
G4
D4
E3
I4
K4
M4
N4
N3
D3
D5
D2.5
E1.5
G5.6
G3
I3
K3
N2
C5
D6
D2
E2
G5.4
G2
I2
K2
L1
M1
C4
D1
E1.3
G5.2
N2
CY
CW
C3
E1
G1
B5
B6
C2
GM
I1
J1
K1
B4
EM
C1
F7
B3
NB
F6
B2
F1
B1
F2
F3
F4
F5
● CURRENT PROFILING STATIONS
■ WATER LEVEL GAUGE

Figure 4-7: Locations of current profiling stations in 1978.

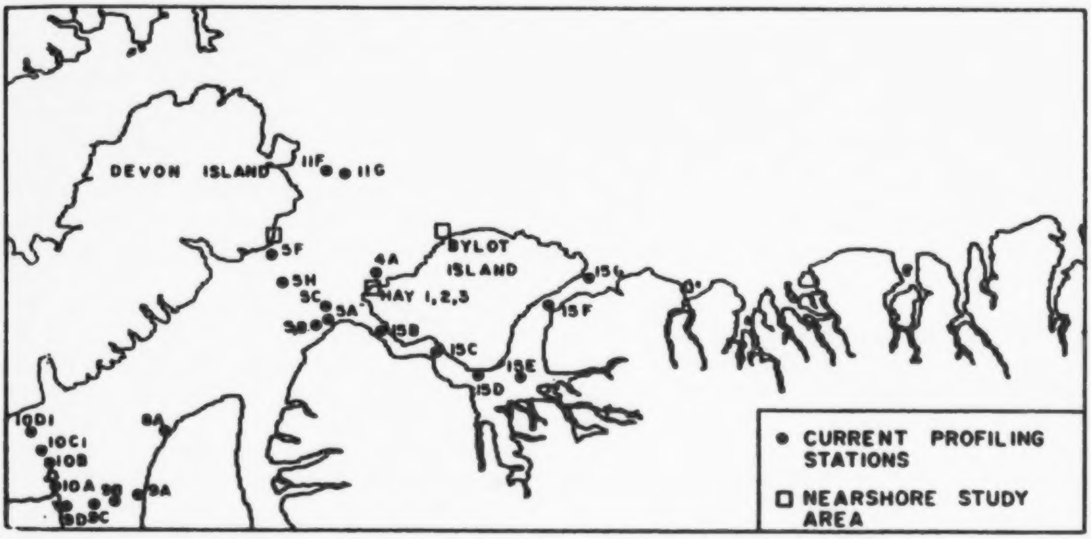

DEVON ISLAND
11F
11G
5F
4A
BYLOT ISLAND
5H
5C
5A
HAY 1,2,3
5B
15B
15G
15F
15C
15E
15D
10D1
10C1
10B
10A
8A
9B
9A
9D
9C
● CURRENT PROFILING STATIONS
□ NEARSHORE STUDY AREA

Figure 4-8: Locations of current profiling stations in 1979.

apply only to velocities relative to the ship with additional uncertainties arising from measurement of the ship's velocity. With available ship positioning equipment (radar and Satellite Navigation) it was only possible to measure ship velocities to an accuracy of 20 cm/s at distances of 10 km or less from shore. At greater distances, the uncertainties became so large that the data is of little value for determining absolute currents.

From July 25 to October 6, 1978, a total of 152 individual current profiles were taken at 50 stations as shown in Figure 4-7. Due to the disappointing accuracies obtained, the current profiling component was reduced in 1979. A total of 26 current profiles were measured, all at different locations (Figure 4-8) between September 1 and September 11, 1979.

4.5 Water Level Measurements

Water level measurements were obtained in Johnson Bay, Devon Island (see Figure 4-9 from August 22, 1978 to May 12, 1979, a period of 263 days. The instrument used was an Applied Microsystems Model TG-12A, designed to measure sea level variations to an accuracy of ± 0.2 cm using a bottom-mounted pressure sensor. However, an internal fault in the instrument limited accuracies to ± 1 cm (Birch, 1980).

4.6 Nearshore Physical Oceanographic Studies

From the 1978 shipboard observations, evidence of intense and often complex circulations in nearshore areas were noted. However, shipboard operations were necessarily limited by the lack of detailed nautical charts and the often difficult ice conditions in these zones. In the summer of 1979, studies of the physical oceanography of nearshore zones were conducted from shore-based camps, using small inflatable boats. The study areas chosen were located at Cape Warrender, Cape Fanshawe and Cape Hay (Figure 4-9).

Data collected for the nearshore studies included surface current measurements, CTD profiles and local shore wind measurements. The current measurements were obtained by tracking surface drifters designed to simulate oil spill movements; these consisted of several nylon-covered hoops attached to one another and a small radio transmitter. The radio transmissions were detected with a receiver (manufactured by Novatech Ltd.) located in the tracking boat, providing an effective means of finding the oil spill followers. The boat was then positioned by means of a Del Norte microwave position system or other means. The accuracies of the velocity determinations were ± 3.5 cm/s (Birch, 1980a). Typically two to five oil spill followers were tracked simultaneously over periods of several hours.

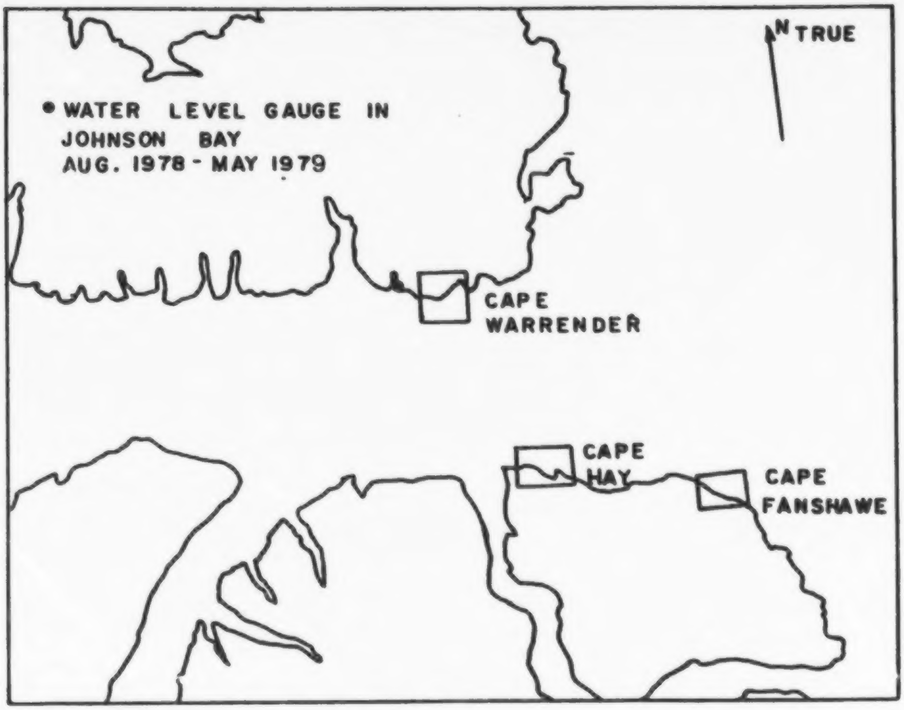

N TRUE
• WATER LEVEL GAUGE IN JOHNSON BAY AUG. 1978 - MAY 1979
CAPE WARRENDER
CAPE HAY
CAPE FANSHAWE

Figure 4-9: Locations of nearshore study areas in the summer of 1979 and the water level gauge operated from August 1978 to May, 1979.

5. RESULTS

5.1 Introduction

Many different oceanic phenomena, which together encompass a wide range of spatial and temporal scales, combine to produce the circulation observed in the study area. The various phenomena can be divided according to their scale sizes into several broad categories, following Monin et al (1977):

(1) Small-scale phenomena (periods ranging from fractions of seconds to tens of minutes; lengths scales from 1 cm to 100 m) including surface waves, internal waves and turbulence.

(2) Mesoscale phenomena (periods of hours to a day; lengths from 0.1 to 10 km), including tidal currents and inertial oscillations.

(3) Synoptic variations (periods of a few days to several months; length scales from 10 km up to basin size), including variations in major circulation features such as the Baffin current.

(4) Seasonal variations (yearly period and its harmonics; length scales up to basin size), including variations related to annual changes in ice cover.

(5) Year-to-year variability (periods in excess of one year to ten years; length scales up to basin size).

(6) Secular variability (periods in tens of years), related to climatic variations of the same periods.

Using data collected in the course of the present study and historical data, it is possible to assess, in order of increasing confidence, year-to-year variability, seasonal variations, synoptic variations and mesoscale phenomena. The data base is far too short for resolving secular or century-to-century variations, while the sampling rate was loo low to resolve most of the small-scale phenomena.

For the purposes of this report, the results will be heavily weighted towards the circulation of the surface and upper portion (tens of metres) of the water column. At these levels, the oceanic circulation is important in transporting pollutants, sea-ice and icebergs. As well, this constitutes an important zone of biological activity.

Typical auto-spectra of fixed-location current measurements for depths of approximately 35 m are displayed in Figure 5.1-1. The spectral values are band-averaged, kinetic energy spectral densities, presented as the sum of the spectral density of each current component. In order to produce approximately even spacing in the logarithmic frequency scale, the degree of band-averaging is variable, increasing from a minimum of three at the lower frequency extreme (standard error of 58%) to in excess of one hundred (standard error of 10% or less) at the higher frequencies. The spectra are plotted with frequency-times-spectral density as the ordinate and the logarithm of the frequency as the abscissa. This display has the advantage that the area beneath the plotted curve represents contributions to the variance for any frequency range chosen.

The general character of all the spectra is similar with a broad synoptic scale peak and narrower peaks at the semi-diurnal and diurnal frequencies. The synoptic peak ranges over periods from 2 to 90 days with the largest levels generally occurring between 3 and 30 days. The individual peaks superimposed on the broad, overall synoptic peak are not statistically significant due to the limited amount of band averaging which is possible at these low frequencies. However, the broad synoptic peak taken as a whole, dominates the spectrum, often accounting for over half of the total variance.

The peaks at the semi-diurnal and diurnal frequencies are narrow but often intense, particularly in the semi-diurnal band which contains periodic variations due to tidal currents and inertial oscillations. The level of the diurnal spectral values are generally lower and, in some areas, these are not statistically significant.

For frequencies greater than the 2.0 cycles per day, the spectral levels fall off rapidly. The contributions from the resolved portion of the high frequencies containing the small-scale phenomena are low, amounting to less than 5% of the total variance. Nevertheless, some of these small-scale phenomena may be of importance: for example, internal waves in nearshore areas with large amounts of brackish surface water due to land run-off of fresh water, as discussed in Section 5.6.

The largest contribution to the variance arises from the synoptic variations. This broad band can account for up to 90% of the total variance depending on location: for measurements sites located in strong, well-defined current regimes, the synoptic variations are larger than for those sites in areas that do not have such large-scale currents (compare, for example, the spectra of stations 2 and 10; the former is located in a region of strong southwesterly flow past Devon Island, while the latter is in an area of weak currents of flow). The synoptic variations are associated with changes i;n these current regimes, either shifts in the locations of the current itself or internal changes in the speed or direction.

Significant changes in the spectral levels appear to occur with the seasons, possibly related to the seasonal variations in ice cover. The spectral levels are higher in the generally open water period from August to September inclusive than in the largely ice-covered period from October to July, for the same measurement sites. These seasonal changes are observed in both the synoptic band and the semi-diurnal band. The seasonal change in the latter can be largely attributed to the reduction of wind-generated inertial oscillations during ice-covered periods.

Seasonal changes in the level of the synoptic variations are not well understood. These changes could result from the reduced coupling between the wind and near-surface water motions due to the presence of winter ice cover or, alternatively, they may be indicative of seasonal changes in the larger-scale outflow of Arctic Ocean water into and through Baffin Bay.

In the detailed description of the circulation which follows, the main circulation features are described by sub-regions, together with their variability found at synoptic scales (Section 5.2). The higher frequency tidal currents and inertial oscillations are presented in Sections 5.4 and 5.5 respectively, while seasonal variations are discussed in Section 5.7, and year-to-year variations, as determined from historical data, are presented in Section 5.8. The circulation features of near-shore zones are discussed separately in Section 5.6, while information about the circulation and properties of the deeper waters are found in Sections 5.3 and 5.9.

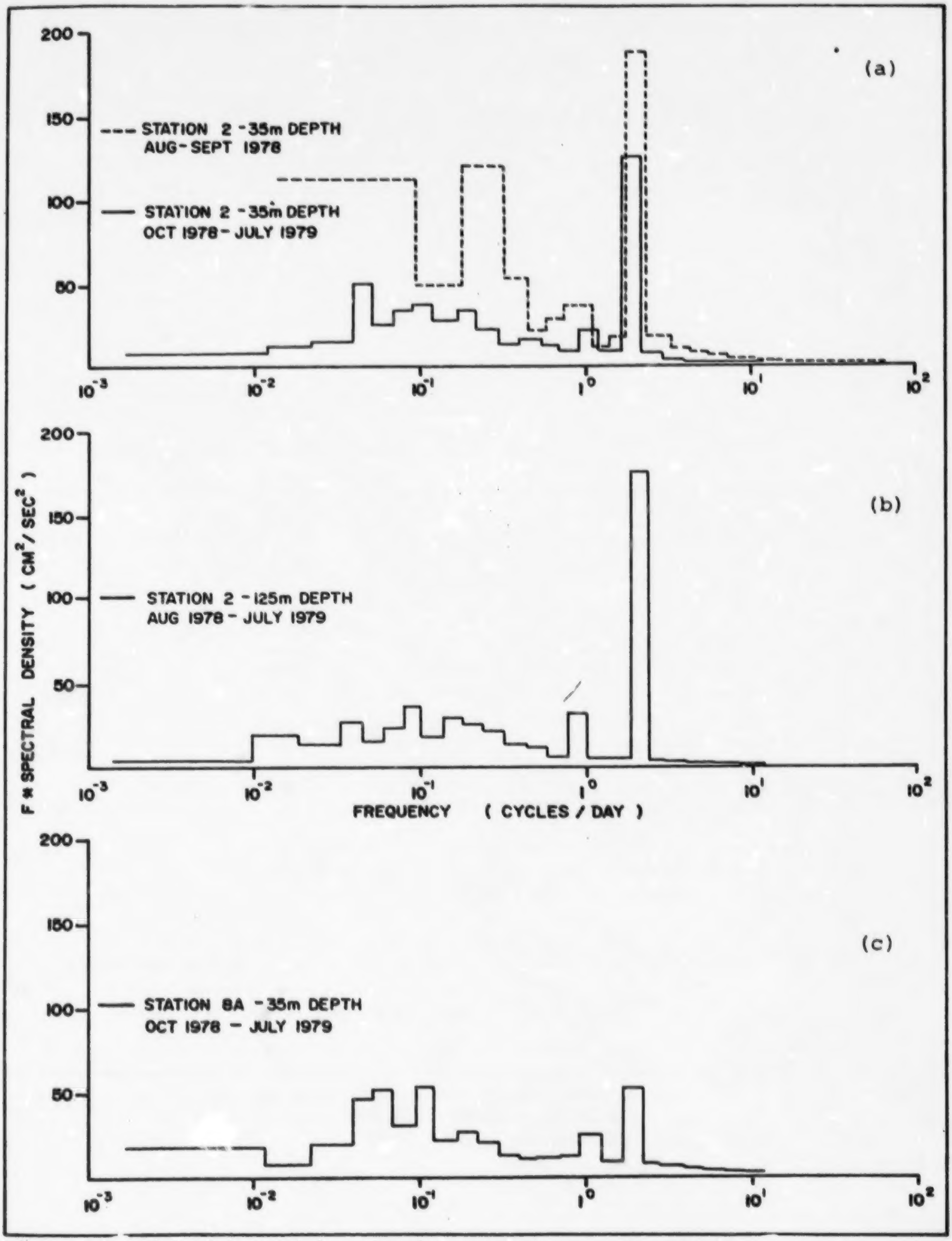


Figure 5.1-1 (a), (b) and (c): Kinetic energy spectra of currents at (a) station 2-35 m, (b) station 2-125 m and (c) station 8a-35 m depths.

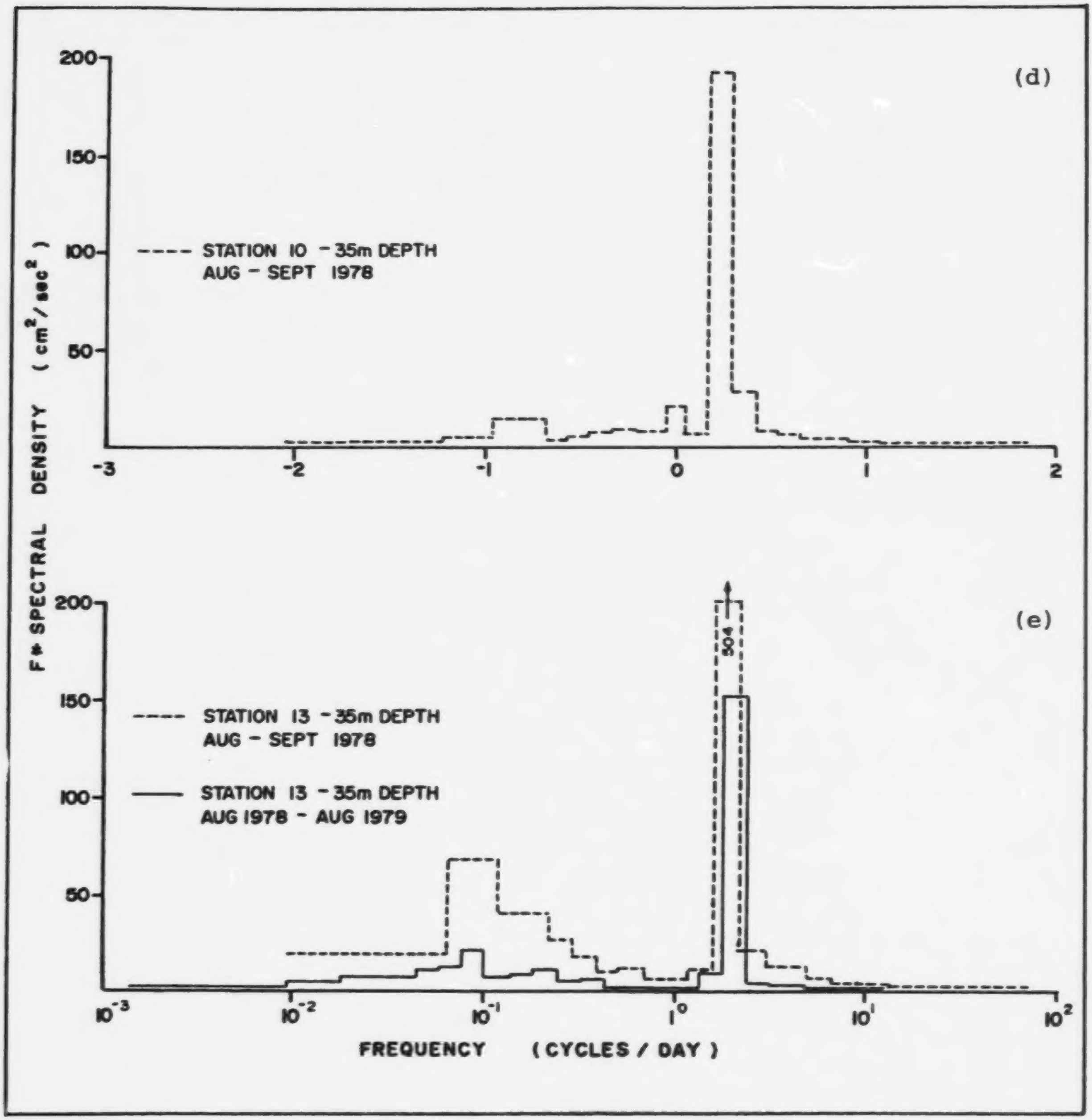


Figure 5.1-1 (d) and (e): Kinetic energy spectra of currents at (d) station 10-35 m depth and (e) station 13-35 m depth.

5.2 Near-Surface Circulation Patterns

A knowledge of surface and near-surface circulation is required for understanding the movement of sea-ice, icebergs and any oil or other pollutants which may be accidentally released. Depending on the physical dimensions of the object being moved by the water circulation, current information is required to varying depths. For large icebergs, information on currents to depths of 200 m may be needed while for oil spills, knowledge of the circulation is often required for only the upper few metres of the ocean. Bearing in mind these widely varying requirements, the description of the surface and near-surface circulation is presented in a general manner. The description is based largely on the 1978 and 1979 data collected for the purposes of the present study. In particular, emphasis is placed on currents measured by satellite-tracked drifters representative of flows between 4.6 and 11 m, data from the uppermost current meter set at a nominal depth of 35 m, and surface dynamic heights relative to the 300 decibar level computed from CTD data.

To aid in the description of the circulation of the study area, several regions or sub-areas have been identified where the circulation appears to have a common feature or pattern dominating the local flow. The boundaries of these regions are indicated in Figure 5.2-1 by the lightly-shaded broad lines; the regions themselves are designated by circled numbers. As well, the areas within 10 kilometres of the coastline are darkly shaded; this separates the offshore and nearshore circulation zones. The width of the nearshore zone is somewhat arbitrary since only three nearshore sites were studied in detail during the course of the experiment. From these studies, significant differences were observed in the circulation between the nearshore zones and adjacent offshore regions. These differences include small-scale spatial variations, enhanced tidal motions, and motion due to the existence of local wind regimes which can differ markedly from those offshore.

Include in Figure 5.2-1 is a schematic representation of the major near-surface circulation features. The dominant southward flow is clearly evident through much of the study area, with many of the strong flows being relatively narrow in width. Much variability is exhibited in many of the circulation features: this includes transient eddy-like features appearing off eastern Bylot Island and a varying penetration of the southward flow into eastern Lancaster Sound. Because of the combined variability and small-scale features of the circulation, the currents shown in Figure 5.2-1 provide a much over-simplified description of the mean circulation. At any given time, the circulation patterns may differ considerably from those shown in Figure 5.2-1.

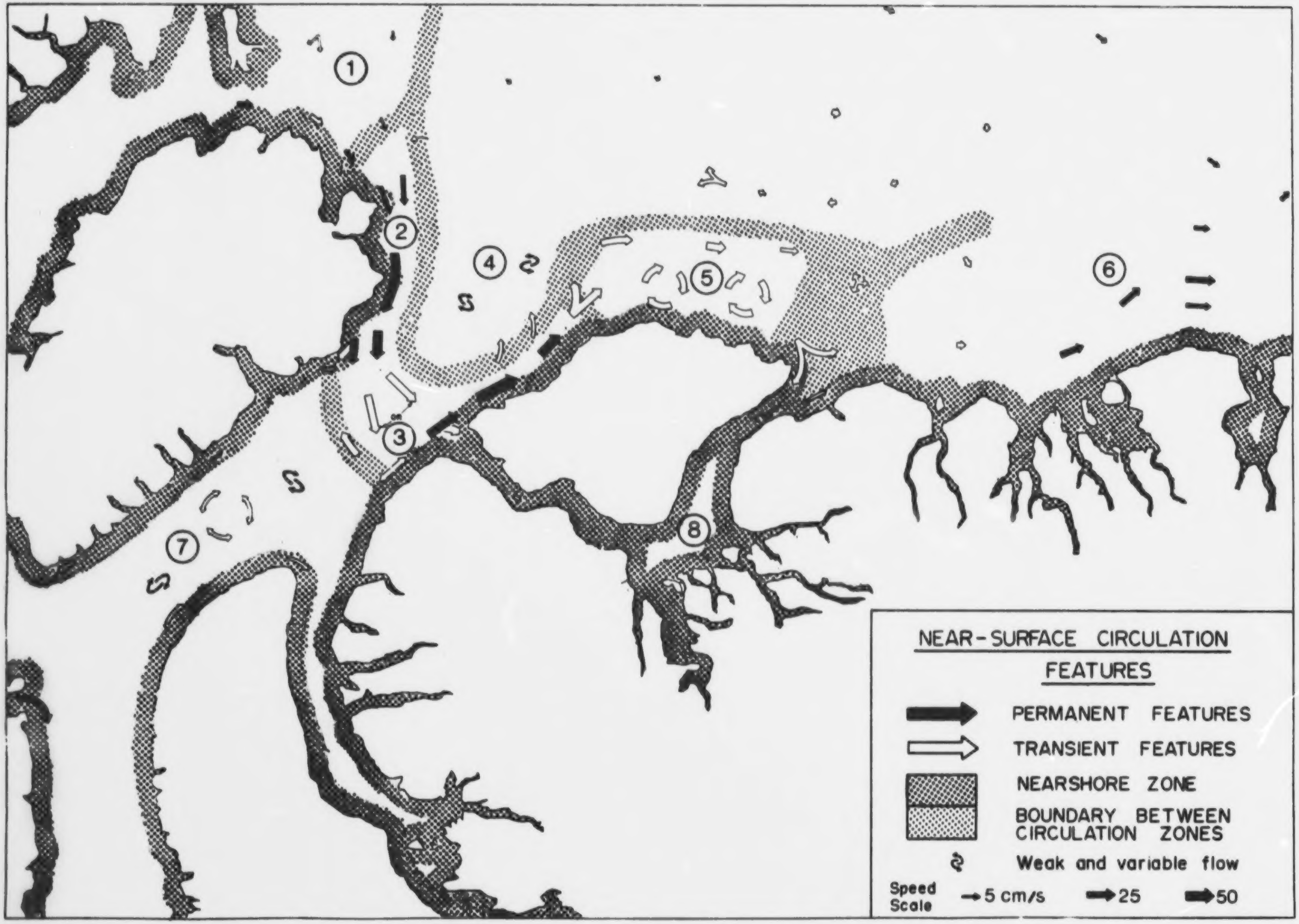

①
②
③
④
⑤
⑥
⑦
⑧
NEAR-SURFACE CIRCULATION FEATURES
PERMANENT FEATURES
TRANSIENT FEATURES
NEARSHORE ZONE
BOUNDARY BETWEEN CIRCULATION ZONES
Weak and variable flow
Speed Scale
5 cm/s
25
50

Figure 5.2-1: A schematic representation of the major near-surface circulation features. The circled numbers identify sub-areas of circulation.

5.2.1 Northern Boundary Zone

This zone represents the northern limits of the physical oceanographic study area. The area includes the waters to the north of Devon Island, Jones Sound, and the 1979 CTD line 2 extending from Lady Ann Strait to Greenland. We will begin with a review of the historical data, then discuss the data collected during 1978 and 1979.

Historical Review

The general surface circulation of Jones Sound has been known for many years. In 1906 Mecking described the circulation - a net outflow to the east through Jones Sound and Lady Ann Strait with an inflow of water through Glacier Strait. Kiilerich (1939) calculated a geostrophic flow of about 10 cm/sec through Jones Sound to the east. Later publications, such as Bailey (1957) and Herlinveaux (1974), have agreed with the general circulation pattern but estimates of the volume transport through Jones Sound have varied. Two of the most recent estimates by Collin and Dunbar (1964), and Palfrey (1968), set the net transport at roughly 0.3 x $10^6 m^3$/sec to the east; whereas Muench (1971) when reviewing the latter's data inferred a net westward baroclinic flow, and found an eastward flow in 1963. Tidal currents may have affected previous transport calculations. Direct, long-term current observations will be necessary before one can accurately determine volume transports in this area.

Barber and Huyer (1977) reviewed the data collected by the CCGS Labrador over a five day period in September 1963. The data consisted mainly of measurements of temperature, salinity, and dissolved oxygen. Barber interpreted the salinity data to imply a strong movement of water into Jones Sound through Glacier Strait and an outflow through Lady Ann Strait, with a "considerable continuity in the total movement". He also interpreted a net inflow from the west and a cyclonic gyre in the portion of the sound west of 84°W. The deep water of Jones Sound was relatively warm (-0.1°C) and saline (34.4°/oo), similar to water found off Philpots Island, and Barber felt that the deep water in Jones Sound originated in Baffin Bay. He presented a simple model of easterly flow of low salinity surface water above the halocline, and weak westerly flow of saline water from Baffin Bay at depth. The 1963 data also indicated a concentration of high salinity water along the south and west coasts of Coburg Island. Barber did not attempt an explanation for this; however 1978 and 1979 data collected by Arctic Sciences Ltd. suggested that this water may also have been of Baffin Bay origin.

1978 and 1979 Observations

The summer near-surface waters of the northern boundary zone can be separated into two categories on the basis of temperature and salinity distribution: warm, saline surface water offshore; and fresher, colder water nearshore. Figure 5.2.1-1 illustrates the summer 1979 vertical temperature and salinity structure for line 2, which extended across northwestern Baffin Bay between Lady Ann Strait and Greenland. Only the data to 200 m has been plotted. The temperatures near 0°C at about 200 m depth are due to the presence of the deep Atlantic Layer. The cold core between roughly 200 and 50 m depth is Arctic Water (see Muench, 1971). It is believed that this cold core is maintained yearly by convection during winter ice formation. Above about 50 m is an upper variable layer. During summer this layer is heated by solar radiation and its salinity is reduced by runoff and ice melt. Convection during winter ice formation destroys this upper layer.

The temperature and salinity characteristics of the surface water in this region during the summer of 1979 can best be seen in Figure 5.2.1-2. Offshore is the warmer upper variable layer; nearshore and inside Jones Sound the surface waters are colder and less saline. The colder, fresher nearshore water is usually attributed to Arctic Water which flows through Smith and Jones Sounds (see Muench, 1971), p. 38). Some or all of the Smith Sound outflow moves south into Jones Sound through Glacier Strait. The temperature and salinity characteristics of the water in Glacier Strait suggest that it is a mixture of Smith Sound outflow and Baffin Bay water (see Figure 5.2.1-3). This reasoning assumes that the Arctic Waters flowing out of Smith and Jones Sound have similar temperature and salinity characteristics, i.e., we assume the upper 100 m of the 1C profile of Figure 5.2.1-3 is representative of Arctic Outflow Water from Smith Sound. The two sounds do have similar temperature and salinity characteristics within the upper 150 m (Muench 1971). The CTD data collected during the summer of 1979 in Glacier Strait also indicated a southwesterly baroclinic flow into Jones Sound. A profiling current meter recorded a northeasterly flow in the upper 50 m in Glacier Strait on August 30, 1978, however this was probably due to the 10 knot wind from the southwest which was blowing at the time.

Very few direct current measurements have been made inside Jones Sound. The 1979 CTD data for stations 1C and 1D indicated a baroclinic component of flow to the east. On August 31, 1978 the profiling current meter recorded strong surface flows to the NNE (42 cm/sec at 35 m) at a location 10 km west of Coburg Island in eastern Jones Sound. This cannot be attributed to the wind at the time. This was in the same area where the 1963 data showed water of relatively high salinity, suggesting that this water may be present through an advective process.

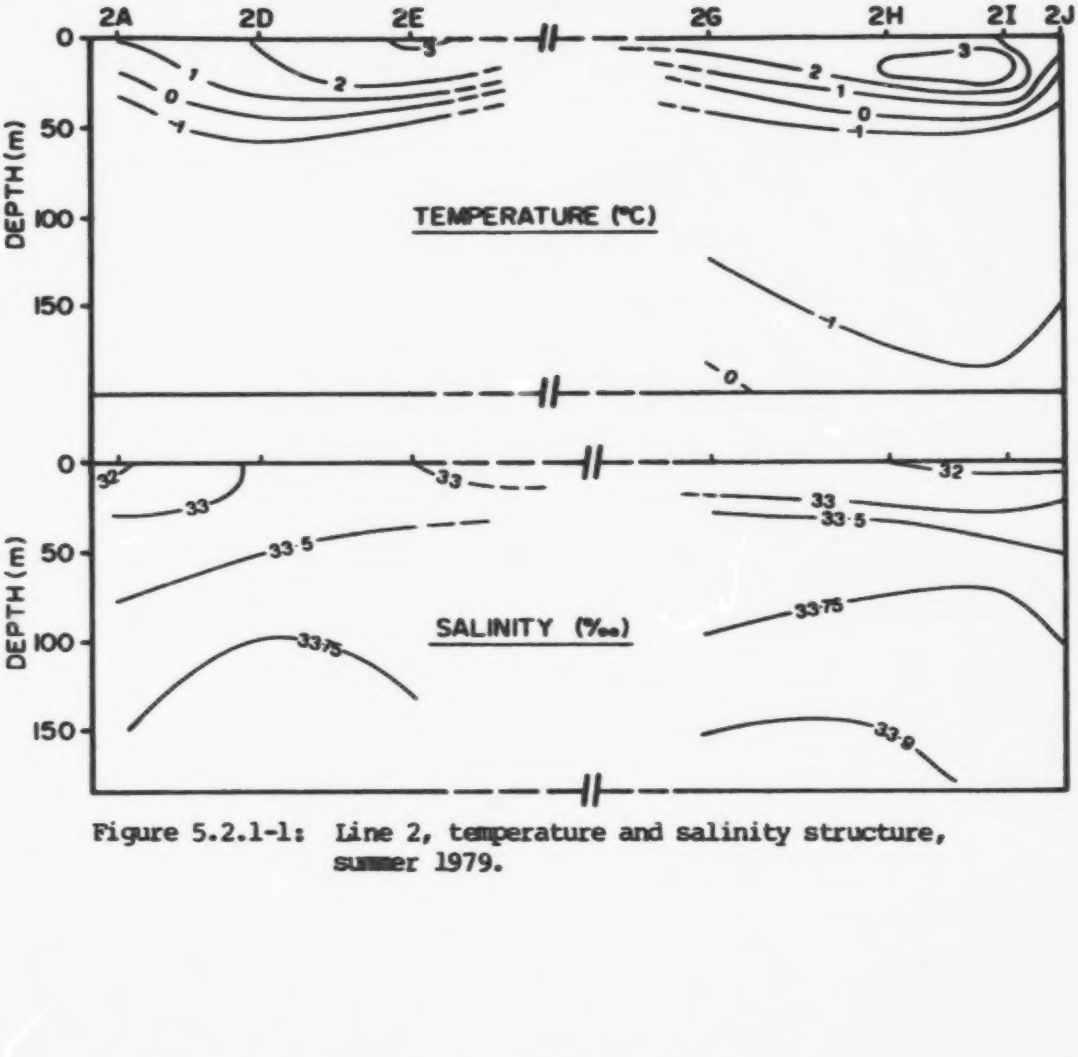


Figure 5.2.1-1: Line 2, temperature and salinity structure, summer 1979.

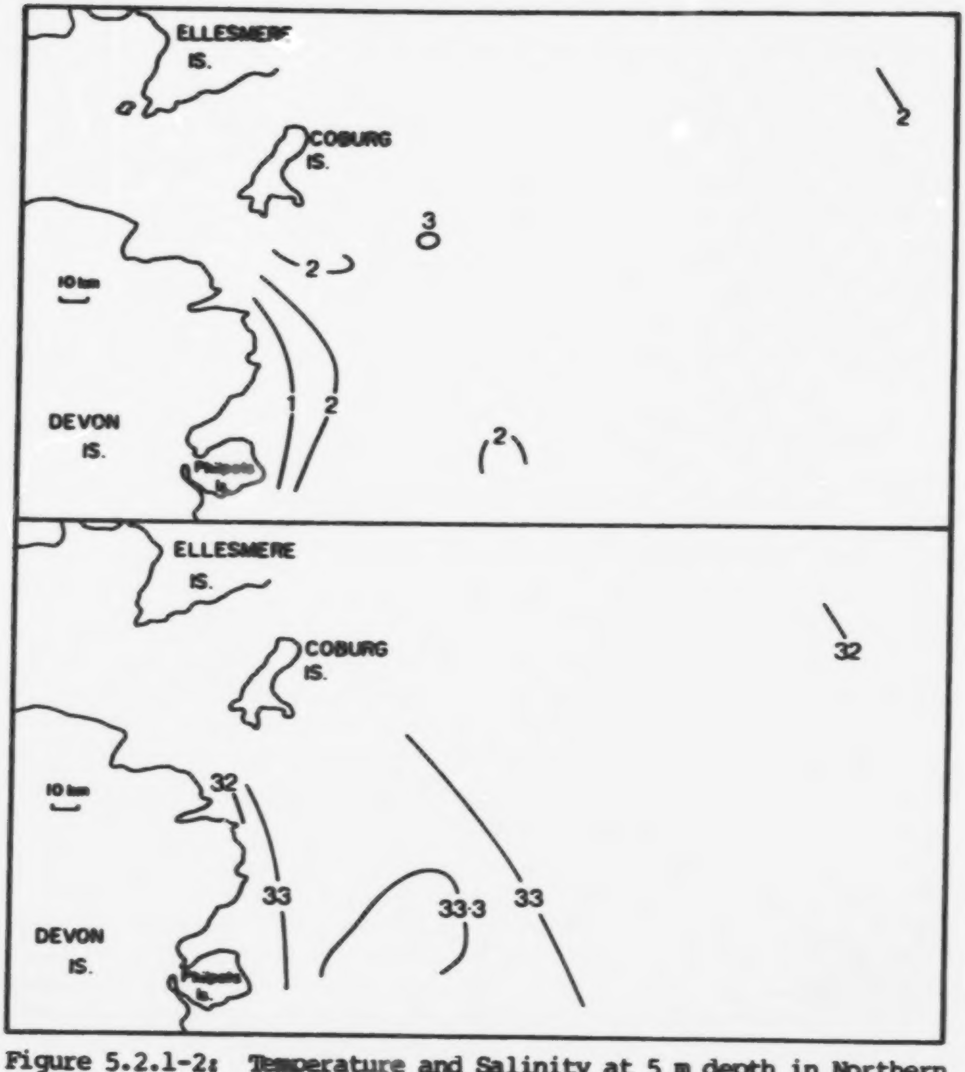

ELLESMERE
IS.
COBURG
IS.
DEVON
IS.
Philpots
Is.
10 km
2
3
2
1
2
2
ELLESMERE
IS.
COBURG
IS.
DEVON
IS.
Philpots
Is.
10 km
32
32
33
33·3
33

Figure 5.2.1-2: Temperature and Salinity at 5 m depth in Northern Boundary Zone, August 18-22, 1979.

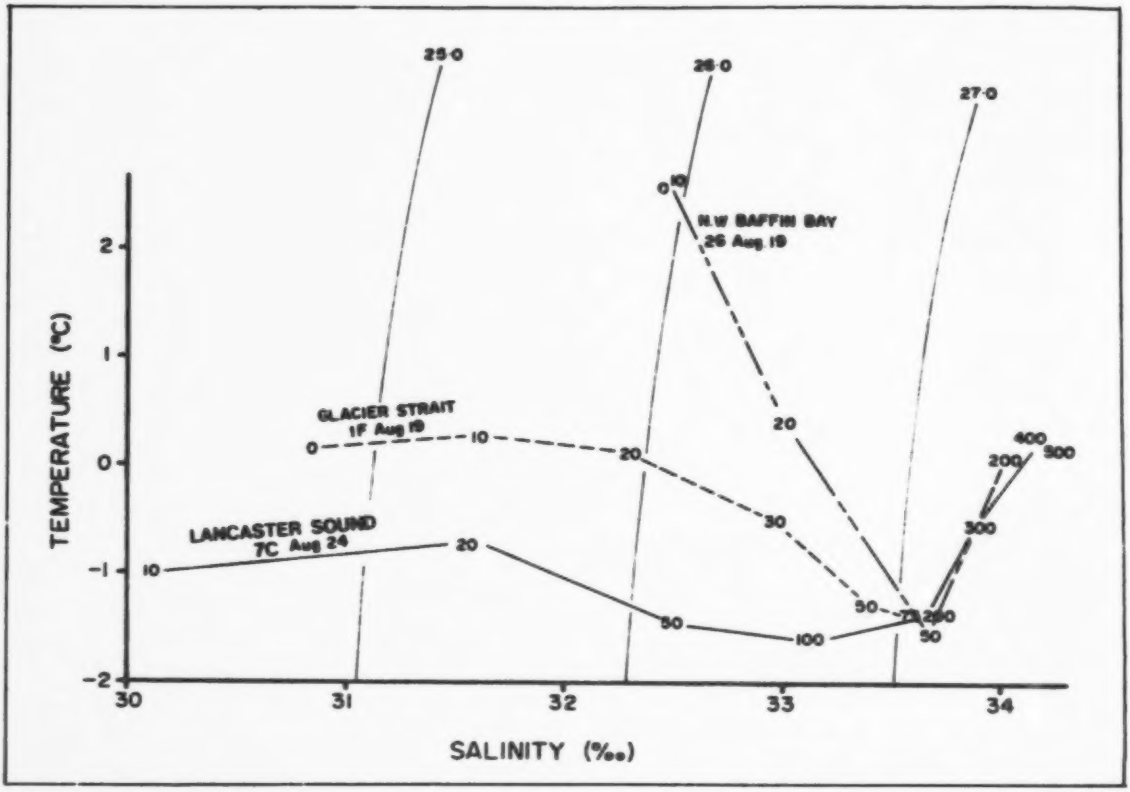


Figure 5.2.1-3: T-S Plot - Stations 1C, 1F, and 2G, 1979.

The circulation of Lady Ann Strait is best derived from the 1979 data. Figure 5.2.1-4 shows the vertical temperature and salinity structure of Lady Ann Strait as well as Glacier Strait, during August 20-21, 1979. Cold, fresh water similar to that found inside Jones Sound is evident along the south side of Lady Ann Strait. Dynamic height calculations for August and September 1979 show a baroclinic flow of 12 and 4 cm/sec respectively to the southeast along the southern side of Lady Ann Strait; however no flow was indicated in the July 25, 1979 dynamic heights. Drifter 1982 released here on August 13, 1979 moved at roughly 58 cm/sec (50 km/day) to the south, alongshore. This could mean there is a significant flow at 300 m, however we have only the results of one drifter trajectory to support this. Figure 5.2.1-4 shows the presence of warmer, more saline water along the northern side of Lady Ann Strait. This water is similar to the surface water found offshore. Its presence suggests that there may be a westerly flow in this area. Drifter 1976 made a shallow penetration of Lady Ann Strait on August 19-20, 1979 (Figure 5.2.1-5). An ice edge across the mouth of the strait may have impeded further motion to the west. On August 29, 1978 the profiling current meter recorded

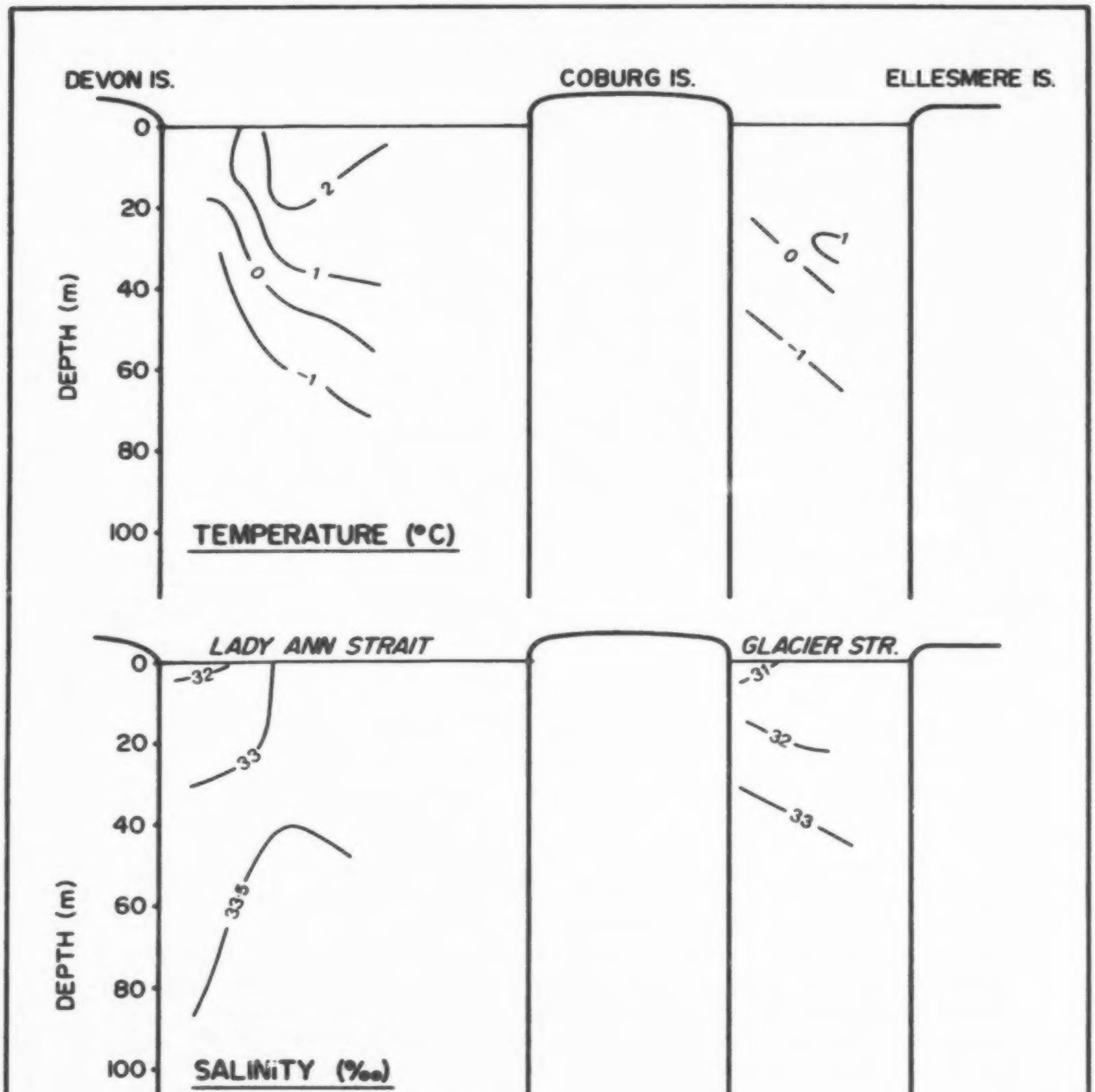


Figure 5.2.1-4: Vertical cross-sections of temperature and salinity over the upper 100 m of Lady Ann Strait and Glacier Strait, August 20-21, 1979.

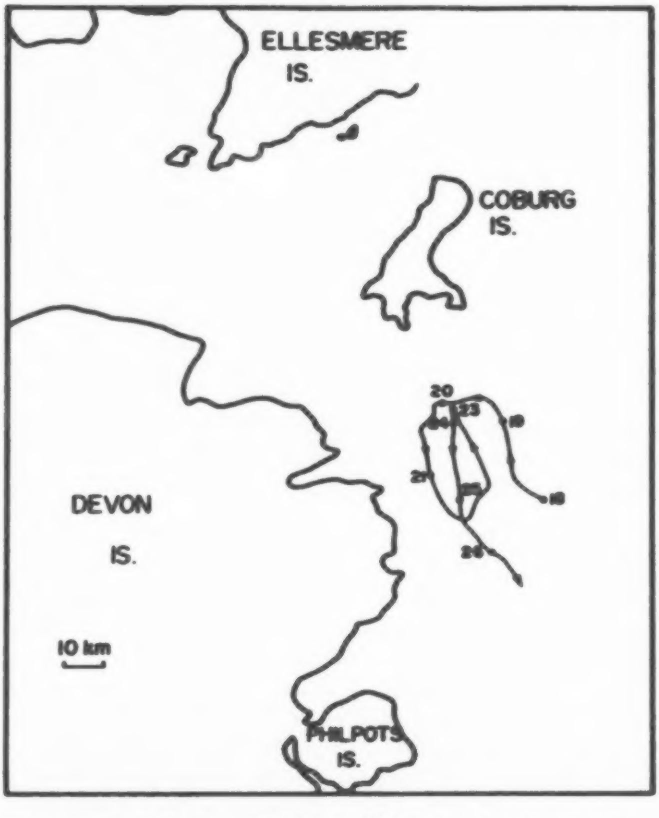

ELLESMERE
IS.
COBURG
IS.
DEVON
IS.
PHILPOTS
IS.
10 km
20
23
19
21
18
26

Figure 5.2.1-5: Drifter 1976 Trajectory, August 18-26, 1979.

westerly flows down to 50 m depth (22 cm/sec at 268°, at 35 m) at a location 5 km off the southern tip of Coburg Island. The water temperature here at 30 m was 1.2°C, similar to the offshore water. The data, admittedly sparse, does suggest that there was a westerly, intrusive flow along the northern side of Lady Ann Strait. The extent of penetration cannot be determined from existing data. It may relate to northerly flow along the west coast of Coburg Island as was observed here on August 31, 1978, and the concentration of saline water observed in September 1963.

In summary, Arctic Outflow water in this area is confined to Glacier Strait, Jones Sound, and a relatively narrow zone along the northeast coast of Devon Island. Offshore, during summer, there is a warm (up to 3°C) surface layer which also extends into Lady Ann Strait along the northern side. Surface flow through Lady Ann Strait is to the southeast along the south side and there are indications that the flow on the north side may be northwest, into Jones Sound. The coastal flow off northeast Devon Island is to the south, alongshore, with surface currents up to 50 km/day.

5.2.2 East of Devon Island

Summer 1979 Data

The most comprehensive data set for the region east of Devon Island was collected during the summer of 1979. We will begin with this, again placing the emphasis on the mean, near-surface circulation.

During summer the surface waters of this region are characterized by warm relatively saline water offshore, becoming colder and fresher as one nears the coastline. Figure 5.2.2-1 shows the vertical temperature structure for CTD line 3 of July 24-27, 1979 which extends due east of Philpots Island. The colder, near-surface Arctic Water Outflow from Lady Ann Strait is confined to within about 10 km of the northeast coast of Devon Island. The distance offshore of the temperature front separating the two surface water masses varies however. The temperature record for the upper current meter at mooring C (1979) shows relatively short period fluctuations between -1 and 2°C, reflecting the movement of the temperature front on and offshore.

The general pattern of surface circulation for the area east of Devon Island during the summer of 1979 is best represented by Figure 5.2.2-2, which shows plots of the dynamic heights using a 300 db reference level. They show a south to southwestward baroclinic flow which becomes more concentrated off Philpots Island. Each of the three plots suggests a large scale meander in the offshore boundary of the flow, centered roughly 70 km east of Devon Island and having a wavelength or diameter of approximately 50 km. Mooring E was in the region where the meander rejoined the main

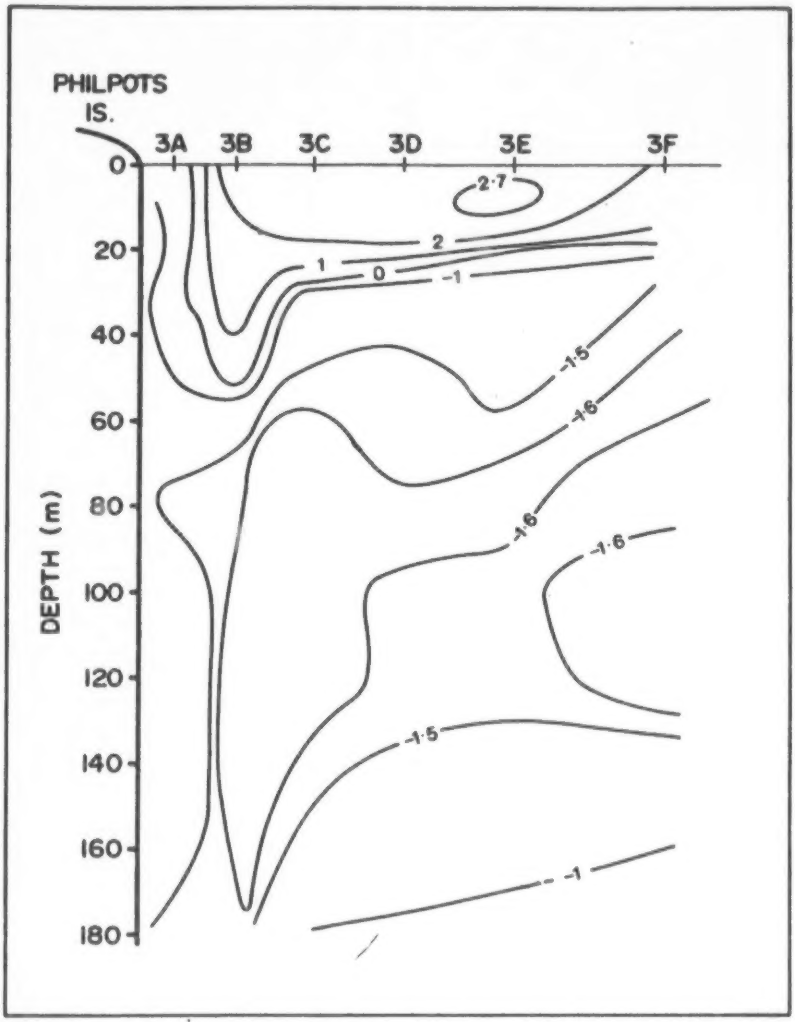


Figure 5.2.2-1: Vertical Temperature Structure Line 3 running E-W off Philpots Island. July 24-27, 1979.

southerly flow. The mean flow recorded here was to the northwest, agreeing with the dynamic height plots. Also, two drifters (#1968 on August 31 - September 4, and #1963 on September 15-18) made counterclockwise turns in the same area, supporting the picture of a meander-type flow rejoining the main current. If the mean northwesterly flow at mooring E is indicative of the same meander flow, then a meander was present during most of August and September 1979.

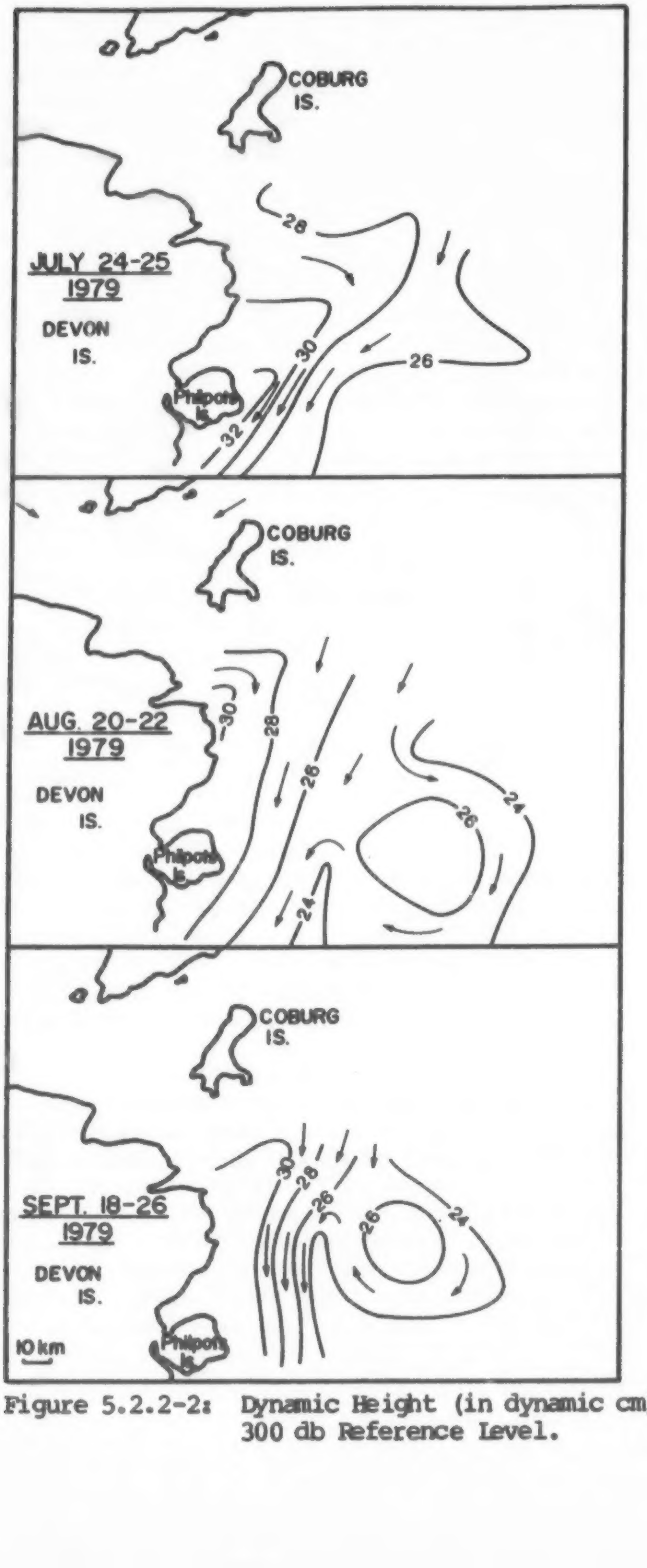

COBURG IS.
JULY 24-25 1979
DEVON IS.
Philpots Is.
28
30
32
26
COBURG IS.
AUG. 20-22 1979
DEVON IS.
Philpots Is.
30
28
26
24
26
24
COBURG IS.
SEPT. 18-26 1979
DEVON IS.
Philpots Is.
30
28
26
26
24
10 km

Figure 5.2.2-2: Dynamic Height (in dynamic cm), Summer 1979. 300 db Reference Level.

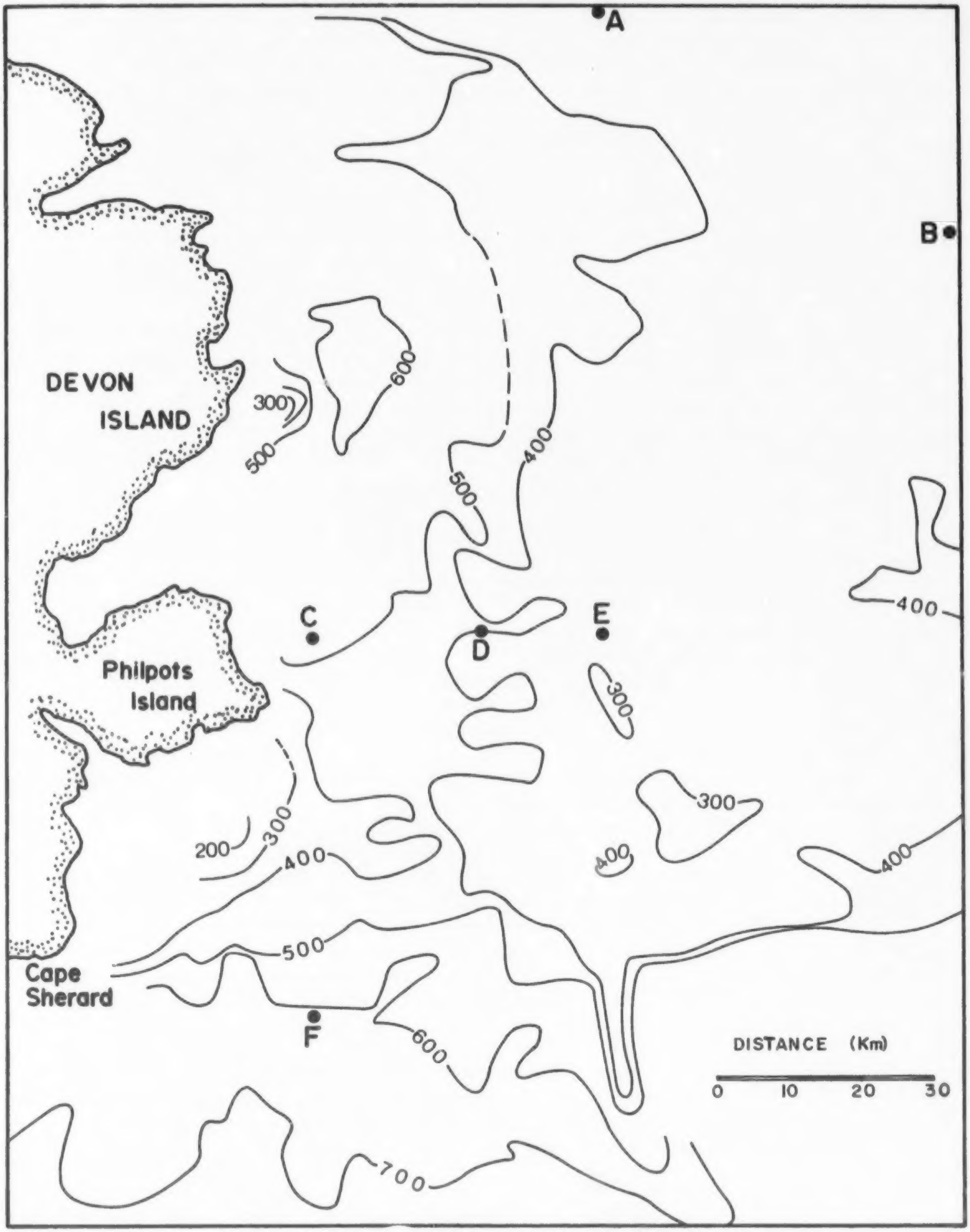

A
B
DEVON ISLAND
Philpots Island
Cape Sherard
C
D
E
F
300
500
600
500
400
400
300
300
200
300
400
400
400
500
600
700
DISTANCE (Km)
0
10
20
30

Figure 5.2.2-3: Detailed chart of the bathymetry in Baffin Bay east of Devon Island, and sites of 1979 current meter moorings. Depths are in meters.

A deep underwater canyon extends from Jones Sound, through Lady Ann Strait, and along the northeast coast of Devon Island, becoming shallower off Philpots Island (see Figure 5.2.2-3). The canyon is about 40 km wide off northeast Devon Island and is up to 600 m deep. To the east of this canyon is a bank, about 80 km wide and 350 m deep, which separates the canyon from the deeper waters of Baffin Bay. The main southerly flow of the Baffin Current in this area is relatively close to the Devon Island coastline, following the path of the canyon. Just to the southeast of Philpots Island the canyon shoals to the depth of the shelf, creating a threshold depth of 400 m here. The depths increase again at the entrance to Lancaster Sound. The meander-type features observed in 1979 occurred over the shelf to the east of the canyon, whereas the main southerly flow coincided with the path of the canyon. This may indicate a possible topographic control in the formation of the meander-like feature.

Moorings A and B (summer 1979) were located in roughly 300 and 400 m depth respectively, in the area to the east of Lady Ann Strait. They were to the east of the deep coastal canyon. The placement of the moorings was such as to provide data on the flow of the Baffin Current as it moved south from Smith Sound and northern Baffin Bay. The vector average flow at mooring A, at 35 m depth, was 6 cm/sec at 256° true (WSW): the mean speed was 9.5 cm/sec and a maximum speed of 33 cm/sec was recorded. At mooring B the average at 35 m was 4.8 cm/sec at 220° (SW); with a mean of 9 cm/sec and maximum of 30 cm/sec. The currents at both moorings decreased with depth. Also, at B, three periods of flow reversal to the northeast were recorded at 250 m, two of which are not apparent in the 125 or 35 m reccords. The 35 m flows at A and B were coherent in speed and direction suggesting that they were both in the same general flow. The flow at A was generally more westerly than at B and this may relate to the previous evidence (Section 5.2.1) of a possible intrusive flow into the north side of Lady Ann Strait. The flows cited are means; at both moorings flow reversals at frequencies of 2 cpd occurred and these were due to the tidal and inertial currents in this area (see Sections 5.4 and 5.5).

Drifters in this area also generally moved south; they exhibited reversals as well but with longer periods, on the order of two days (see for example Figure 5.2.1-5). In particular #1976 between August 13 and August 28, 1979 reversed directions (north-south) six times before reaching the region of intensified flow off Philpots Island and continuing south. The motion of drifter #1982 on August 13 indicated a strong southerly coastal flow within 10 km of the northeast coast of Devon Island. It travelled 50 km in one day (58 cm/sec) and illustrates the strengthening of the coastal flow that occurs as one moves nearer shore. The coastal areas immediately to the north and south of Philpots Island are relatively stagnant however, and drifters entering this region take up to several days to exit and rejoin the main coastal flow.

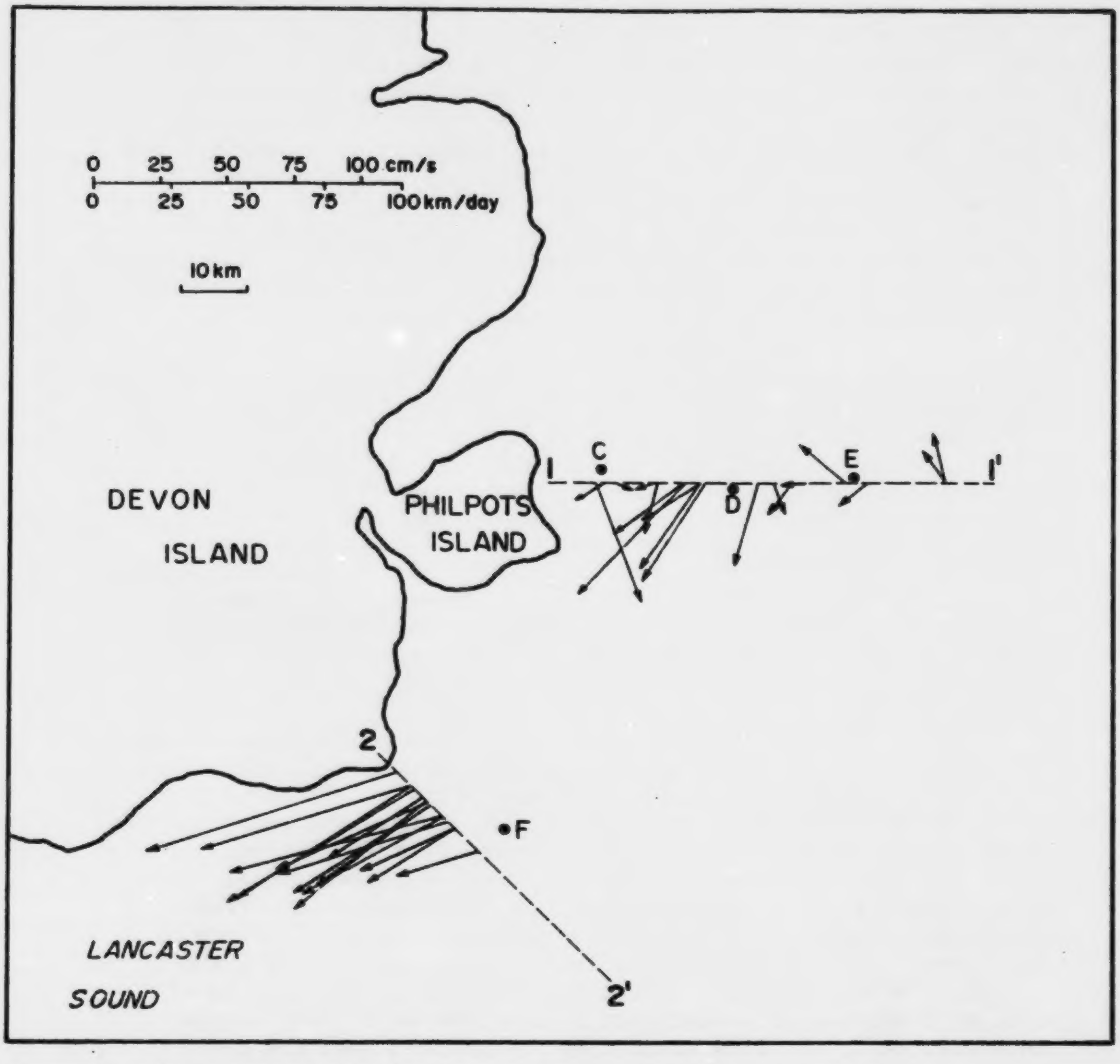

0 25 50 75 100 cm/s
0 25 50 75 100 km/day
10 km
DEVON
ISLAND
PHILPOTS
ISLAND
1
C
D
E
1'
2
F
2'
LANCASTER
SOUND

Figure 5.2.2-4: Velocities of near-surface currents measured by satellite-tracked drifters crossing two sections off Devon Island in 1979.

The Baffin Current is concentrated into a strong coastal current off Philpots Island. Figure 5.2.2-4 (line 1-1') shows vector velocities of all 1979 drifters which crossed the latitude of 75°58'N. The plot depicts a strong flow between about 8 and 35 km of shore, with current speeds of about 40 cm/sec (35 km/day), but occasionally reaching 58 cm/sec (50 km/day). Offshore of this strong current the velocities are much less and are likely to be to the northwest and west; this agrees with the dynamic topography and the meander-like features already mentioned.

The three moorings of 1979 (C, D, and E) are at this same latitude as shown in Figure 5.2.2-4. The flow recorded at mooring D was quite strong and steady southerly at all three depths of 35, 125, and 250 m. The average vector velocity at 35 m at D was 17.5 cm/sec (15 km/day) at 205°, with a mean speed of 20 cm/sec (17 km/day). The flow at D is coherent with depth but is reduced to an average velocity of 5 cm/sec at 250 m and is slightly more westerly at 218°. Apparently mooring D was usually not in the strongest part of the current; however at times speeds up to 40 cm/sec were recorded at 35 m and this suggests that at these times the main flow either moved to include mooring D or else increased overall.

Mooring E (Figure 5.2.2-4) was in the area where dynamic heights and drifter motion suggested a return of the meander to the main southerly flow. The flow at 35 m here during summer 1979 had a vector average velocity of 2.2 cm/sec at 327° but mean speeds averaged 9.8 cm/sec with a maximum recorded speed of 36 cm/sec. No 125 m record exist and only a short record (10 days) for 250 m was recovered but this showed northerly flow as well. This suggests that the eastern edge of the strong southerly current off Philpots Island was between moorings D and E, or approximately 35 km offshore. This agrees with the drifter results of Figure 5.2.2-4. Mooring E also recorded tidal and inertial currents with 2 cpd reversals.

Mooring C was roughly 10 km offshore of Philpots Island and Figure 5.2.2-4 indicates that it was inshore of the main flow. The vector average velocity at 35 m was 18 cm/sec (15 km/day) at 210°, and the mean speed of 24 cm/sec (21 km/day) was less than the speed of the drifters passing with the main current between moorings C and D. The current is coherent in speed and direction at the three meters at C, with speeds reducing with depth. Low frequency clockwise-rotating flow reversals occurred twice with periods of 4 and 5 days, and extending to at least 250 m depth. During the second reversal southerly moving drifters passed within 6 km of mooring C showing no resemblance to the flow at C. During the reversals at C, the flow at mooring D increased (see the N-S components, Figure 5.2.2-5); a cross correlation of the two 35 m low-frequency N-S components shows a significant negative correlation (see Figure 5.2.2-6). As the southerly flow at mooring D increased, the southerly flow at mooring C decreased and became northerly on two occasions. The best correlation occurred with the C record leading D by 3 to 4 days. While the flows at the two moorings are clearly related, the physics of the correlation remains to be determined.

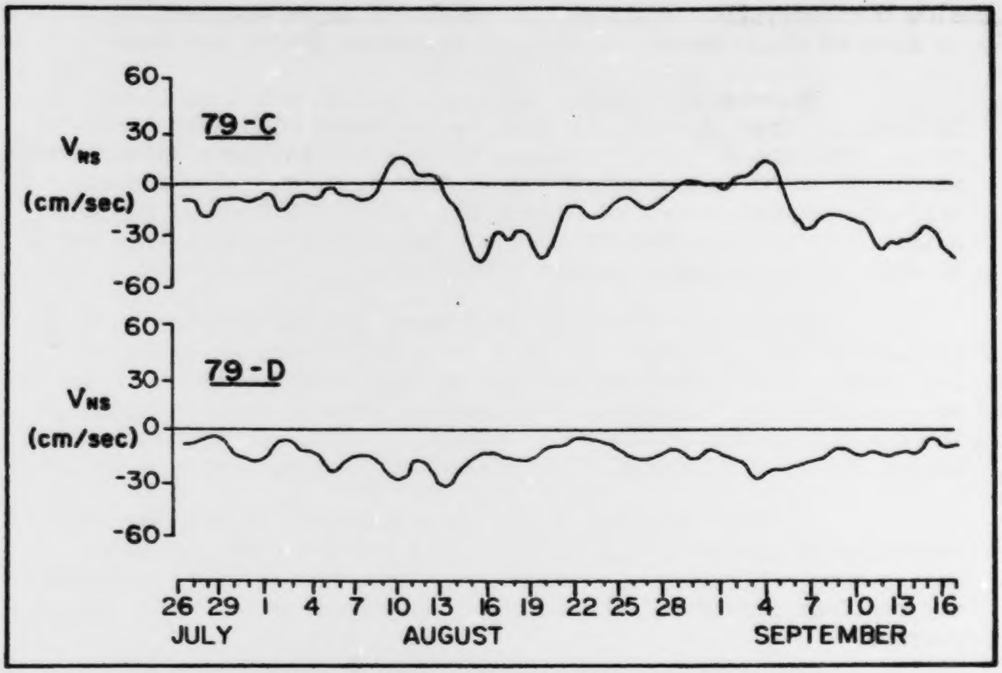


Figure 5.2.2-5: Low pass filtered northerly component of velocity at 35 m depth, stations C and D.

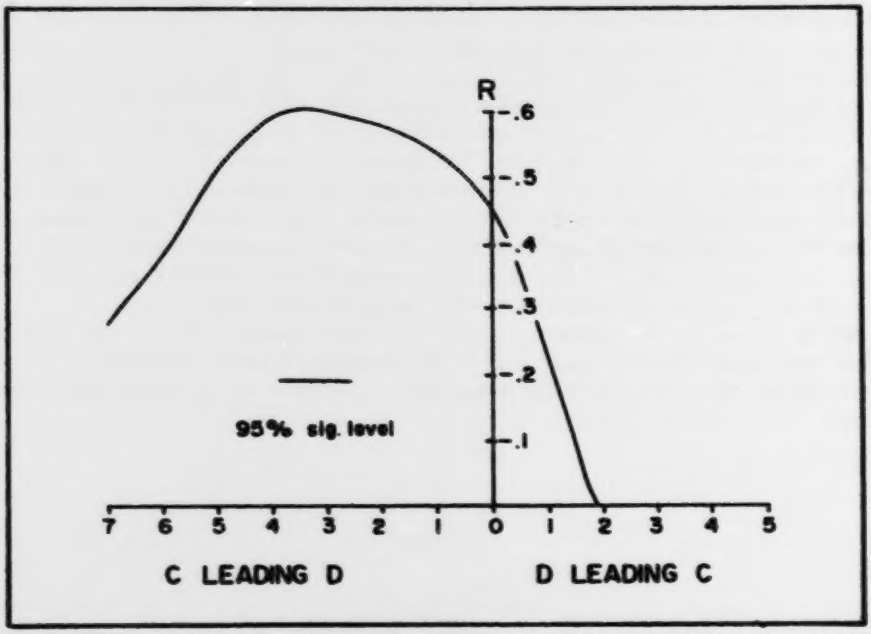


Figure 5.2.2-6: Cross-correlation coefficient (R) versus time lag in days for northerly components measured at stations C and D, 35 m depth.

Mooring C was located near the threshold depth at the southern limit of the deep canyon. At 450 m here the vector average flow was 0.76 cm/sec at 15° with a mean speed of 6 cm/sec. This slow northerly flow could be the result of an estuarine-like process related to Jones Sound, as was envisioned by Barber and Huyer (1977).

The coastal current follows the east coast of Devon Island; off Cape Sherard the flow is southwesterly, into Lancaster Sound. All the drifters released in 1979 off Philpots Island passed within 20 km of Cape Sherard (see Figure 5.2.2-4). The fastest drifters reached speeds of almost 100 cm/sec (86 km/day) and were within 5 km of Cape Sherard. As one moved offshore drifters moved slower; 18 km offshore, speeds were reduced to 28 km/day.

During the summer of 1979 mooring F was located 35 km SE of Cape Sherard (Figure 5.2.2-4). Only the record at 125 m was recovered. The vector average current was 6 cm/sec at 250°; the mean current was 7.5 cm/sec, the maximum recorded was 35 cm/sec. The current direction was quite steady at 250°, however on August 10, 1979 a flow of about 20 cm/sec to the north was recorded.

Off Cape Sherard, where the current turns and begins its intrusion of Lancaster Sound, the depth increases more than 200 meters over a horizontal distance of 3 km. Such a depth increase may manifest itself in some form of topographic steering of the current.

Summer 1978 Data

The 1978 data is in basic agreement with the 1979 results discussed above. The dynamic heights indicate a strong coastal current becoming weaker and more variable offshore. The 1978 CTD coverage did not include the area where the meander(s) of 1979 were observed, so no comparison there is possible. The drifter data is presented in Figure 5.2.2-7 and is compatible with the 1979 data of Figure 5.2.2-4. The westerly flow offshore of Philpots Island may represent meander features similar to those observed in 1979. The 1978 drifter coverage included #347 and #1154 which were deployed 75 and 130 km east of Philpots Island, respectively. From deployment on August 28, 1978 through to September 8 drifter #347 made very little net movement, and #1154 moved very slowly south at roughly 3 km/day. These represent probably the only direct current measurements this far offshore, east of Devon Island, and indicate a very weak net southerly flow. After September 7 both drifters increased speed to the south in apparent response to a wind event at that time.

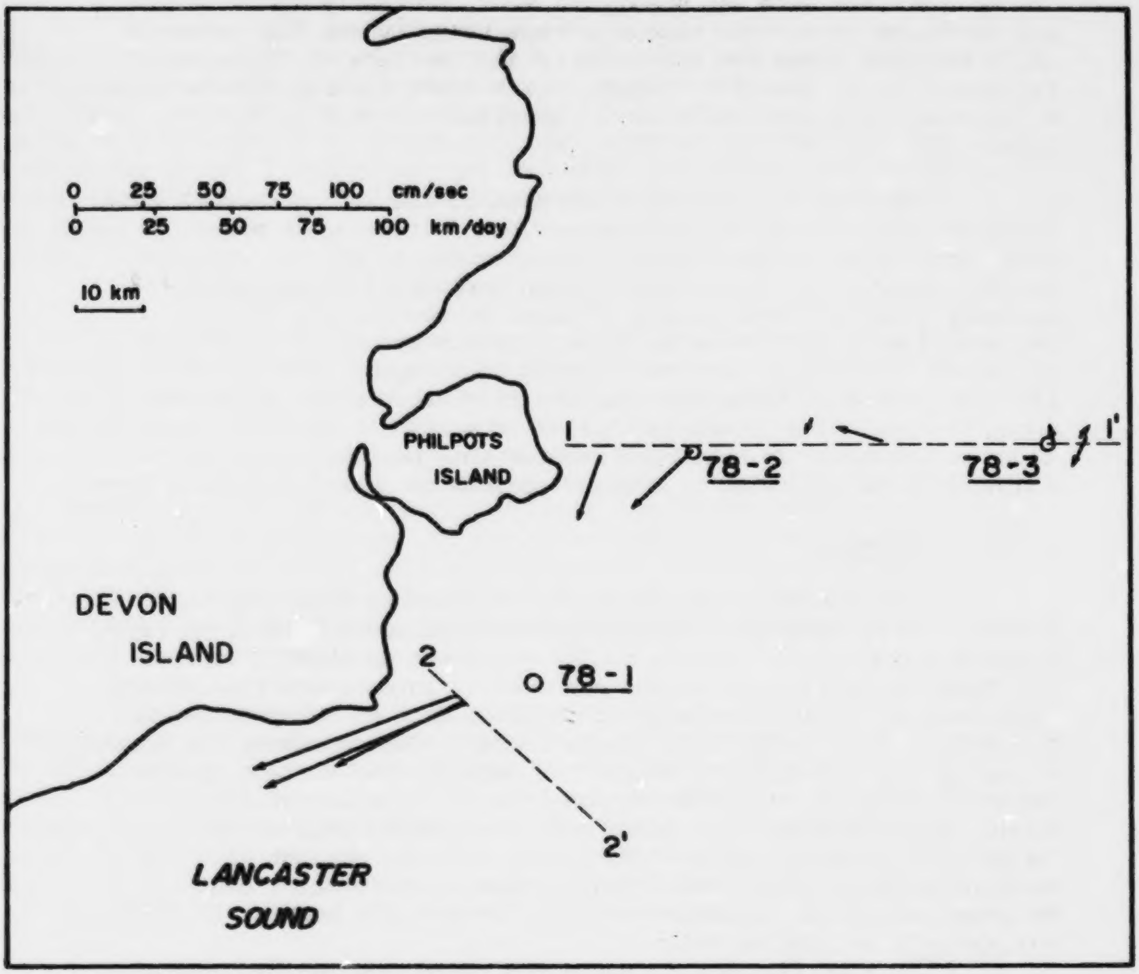

0 25 50 75 100 cm/sec
0 25 50 75 100 km/day
10 km
PHILPOTS ISLAND
1
78-2
78-3
1'
DEVON ISLAND
2
78-1
2'
LANCASTER SOUND

Figure 5.2.2-7: Velocities of near-surface currents measured by satellite-tracked drifters crossing two sections off Devon Island in 1978.

During the summer of 1978 two moorings were deployed off Philpots Island, 78-2 and 78-3 (see Figure 5.2.2-7). Mooring 3 was offshore of the strong current. Only data from 250 m is available. The mean current here was steady but weak, southerly during August and September 1978. The vector average velocity was 3.5 cm/sec at 193°; the mean speed was 6.8 cm/sec with a maximum of 23 cm/sec recorded. As in the 1979 records, north-south reversals occurred at a frequency of 2 cpd, again due to inertial currents and the M_2 tidal flow.

Mooring 78-2 was near the area of the strong coastal flow. The flow here was vertically coherent but decreasing in magnitude with depth, down to the deepest current meter at 250 m. The flow was not steady, but fluctuated between periods of strong southwesterly flow with mean speeds of about 30 cm/sec, and shorter periods of weak northeasterly flow. Maximum speeds of up to 80 cm/sec (70 km/day) were recorded at 35 m depth. During August 1978 the period of these mean current fluctuations (at 35 m) was about 11 days. The record is similar to mooring C of 1979, (located 13 km to the west) in that both records show periods of strong southerly flow separated by shorter periods of weaker northerly flow.

Summary

The surface circulation is dominated by a strong southerly flowing coastal current. To the northeast of Devon Island, at 1979 moorings A and B, the flow is to the southwest at about 9 cm/sec. Off Philpots Island the current has usually intensified to a strong flow about 25 km wide centered 20 to 25 km east of Philpots Island. The surface flow in the core of the current, during summer, is about 40 cm/sec but occasionally reaches 58 cm/sec. The current speeds reduce with depth, to speeds on the order of 5 cm/sec at 250 m depth. Flow reversals can occur near the inshore edge of the current off Philpots Island. Northerly flow was evident at 450 m depth at mooring 79-C. The offshore edge of the current east of Philpots Island was characterized by a large scale meander in 1979 and possibly in 1978 as well.

As the current rounds Cape Sherard it increases in speed (up to 100 cm/sec near surface) and narrows; the core of the current approaches to within 20 km of shore. Current speeds reduce almost linearly with distance offshore of Cape Sherard.

5.2.3 Intrusive Current in Eastern Lancaster Sound

Introduction

The near-surface circulation of eastern Lancaster Sound is dominated by an intrusion of the southward flowing Baffin Current into, across and out of the eastern end of Lancaster Sound. In this section, we shall present the characteristics of this current including a description of its spatial and temporal variations. The description is based exclusively on data collected in the open water season (summer and early autumn) and draws heavily on the results of the summer 1979 program.

Satellite-Tracked Drifter Data

To define the intrusive current, we first consider the movements of 18 satellite-tracked drifters released in the summer of 1979 at various locations within 60 km of the east coast of Devon Island. Fifteen of these drifters followed the intrusive current pattern: moving to the west into Lancaster Sound on the northern side, crossing the Sound and exiting to the east either directly into Baffin Bay (thirteen drifters) or into Navy Board Inlet - Eclipse Sound (two drifters). Of the other three drifters, one failed within a day of the release, another failed after entering the Sound but prior to leaving, while the other was released into the Central Disordered Zone, offshore of the intrusive current, as discussed in Section 5.2.4.

The movements of the drifters released in 1979 are summarized in Figure 5.2.3-1 by shaded areas which contain most of the tracks. Portions of four drifter tracks deviate from these areas. Three of these departed on the northern side of the usual pathway in the vicinity of Cape Warrender; these deviations are thought to reflect smaller scale nearshore circulation features as described in Section 5.6 and are not considered representative of the larger scale offshore circulation patterns.

In the 1979 drifter data, the intrusive current appears in at least two distinctly different modes. The two modes shown in Figure 5.2.3-1 are similar for the northern side of Lancaster Sound. However as the drifters began to turn southward and cross the Sound, significant differences appear. Approximately half (nine of sixteen) of the drifters continued to turn until the flows became generally southeastward as they passed through the middle of the Sound. These drifters then proceeded out of Lancaster Sound returning to Baffin Bay well offshore of the northwestern tip of Bylot Island. The other seven 1979 drifters did not change their directions as much, as they moved offshore of Devon Island, but moved southwestward across the middle of the Sound. All of these drifters travelled to within 15 km of Borden Peninsula, where they then began

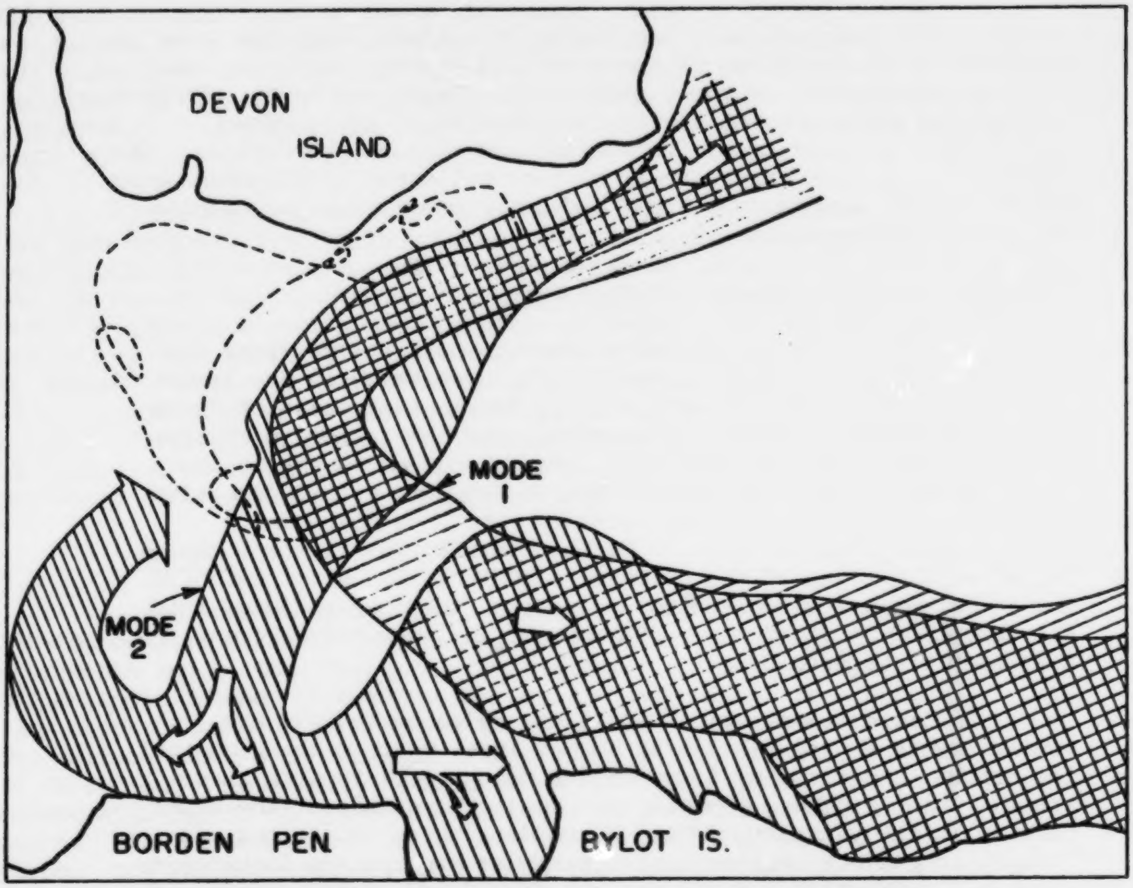

DEVON
ISLAND
MODE
1
MODE
2
BORDEN PEN.
BYLOT IS.

Figure 5.2.3-1: Envelopes containing 1979 drifters tracks divided according to two modes. The cross-hatched areas represent areas common to both modes. Shown separately as dashed lines are the tracks of four drifters which departed from the major flow patterns.

to move either to the east or west. Of the four drifters that travelled eastward, three returned to Baffin Bay along the north side of Bylot Island while one drifter entered Navy Board Inlet. Three drifters moved westward parallel to the coastline of Borden Peninsula and then turned northwards. While one of the drifters failed at this point, the remaining two, upon approaching the middle of the Sound turned eastwards and then southwards again, crossing their previous tracks. One of these drifters entered Navy Board Inlet, while the other exited Lancaster Sound to the east along the northern side of Bylot Island travelling within 2 km of the coastline. In the case of the drifters moving westward along Borden Peninsula turning north and crossing their previous tracks to the southeast, the described movements cannot represent a stable circulation pattern but rather may result from a transition from one mode of the intrusive current to a different one. The circulation of the southern half of Lancaster Sound off Borden Peninsula is discussed in more detail below. First, we will describe the intrusive current in a more quantitative way.

To provide a more quantitative description of the intrusive current, the 1979 drifter velocities were computed at three cross-sections as shown in Figure 5.2.3-2. The characteristics of the velocities through these cross-sections are summarized in Table 5.2.3-1.

Table 5.2.3-1

Velocities of the intrusive current in Lancaster Sound through three cross-sections, based on 1979 drifter velocities. The velocities are tabulated for both modes.

Section	Number of Obs.	Speed (cm/sec)			Direction (T)		
		Max.	Min.	Median	Max.	Min.	Median
A-A'	15	103	30	73	273	212	259
B-B'	16	100	24	67	225	131	157
C-C'	17	117	48	81	144	75	102

As the Baffin Current enters Lancaster Sound from the northeast, the flow appears to narrow and strengthen. To the southwest of Cape Sherard the near-surface currents are typically 70 cm/s in speed and are remarkably uniform in direction with an observed range of only 61 degrees. Another distinctive feature of the flows through section A-A' is the limited extent over which the current was observed: all fifteen drifters passed within a band ranging from 6 to 16 km offshore. In all likelihood, the actual width of the current at any given time was even narrower than the 10 km range observed over the 40 day period of observations in the summer of 1979.

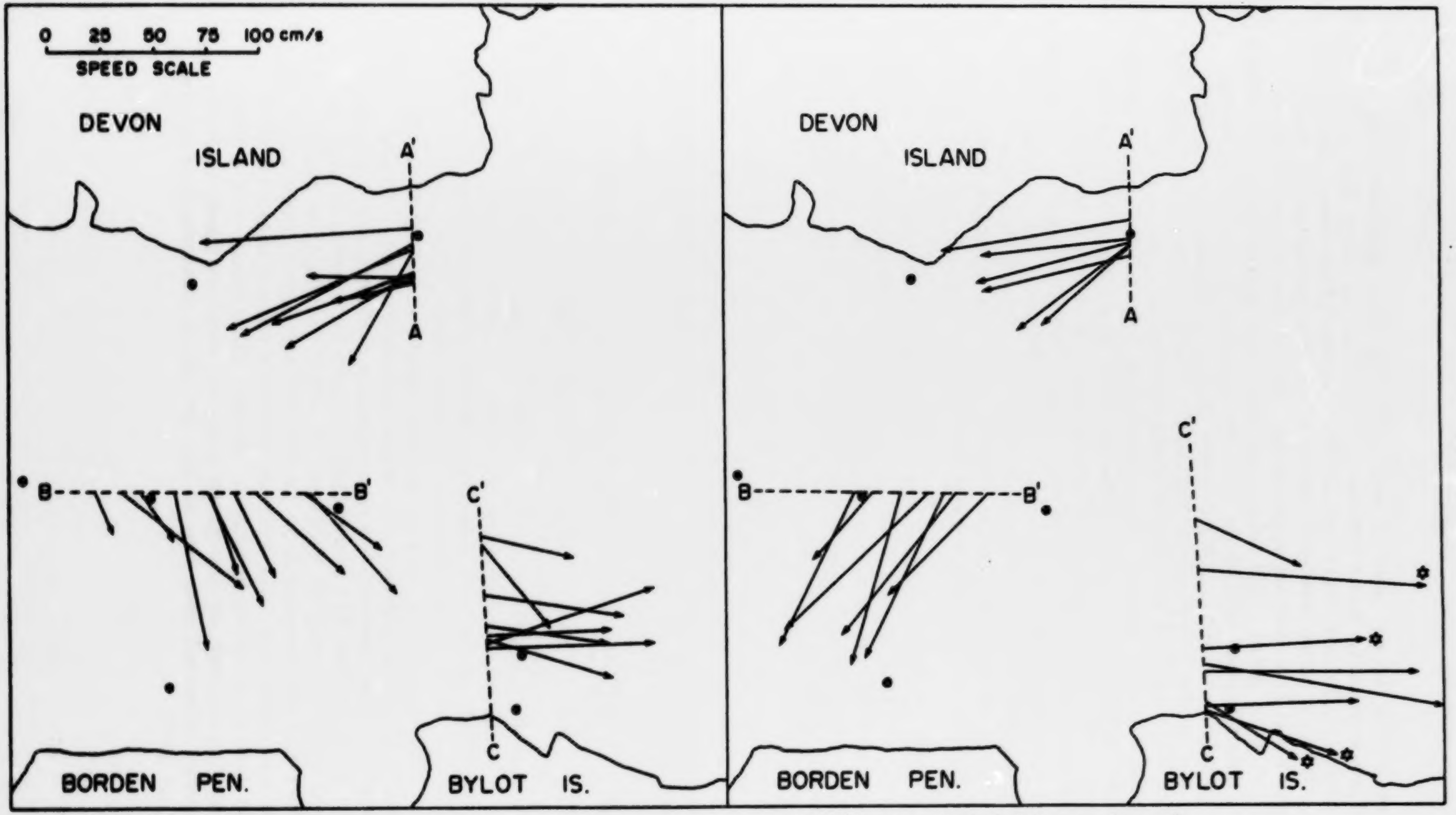

0 25 50 75 100 cm/s
SPEED SCALE
DEVON
ISLAND
A'
A
B
B'
C'
C
BORDEN PEN.
BYLOT IS.
DEVON
ISLAND
A'
A
B
B'
C'
C
BORDEN PEN.
BYLOT IS.

Figure 5.2.3-2: Near-surface current velocities measured by satellite-tracked drifters through three cross-sections of the intrusive current. The velocities are presented separately for each mode of the current. The symbol (*) represents velocities of drifters deployed in western and central Lancaster Sound.

On crossing the centre of Lancaster Sound the flow is more variable in both location and velocity. Drifters crossing from north to south were observed over a 35 km wide section of the centre of the Sound, ranging from 35 to 65 km west of the line joining Cape Sherard and Cape Hay, at mid-Sound. Two patterns of drifter tracks emerge from the 1979 data. In the centre of the Sound the patterns are clearly distinct as (1) south to southeasterly movements or (2) south to southwesterly movements. In the latter case, the flows are usually stronger (median value of the seven occurrences of mode (2) is 87 cm/s as compared to 54 cm/s for the ten occurrences of mode (1).

In the outflow on the southern side of Lancaster Sound, east of Navy Board Inlet the drifter movements were faster than those observed in the centre and northern sections. Both the median (81 cm/s) and maximum (117 cm/s) speeds are largest for this section. Drifter passages through the section occur over a range of 33 km with the closest crossing being within 4 km of the shoreline. For drifters following pattern (1) of the intrusive current, there is a distinct tendency for the drifters to remain further offshore (at section C-C'). Drifters in this mode passed through the section between 11 and 30 km offshore. Drifters originating east of Devon Island which followed pattern (2) of the intrusive current and those drifters which were deployed further to the west in Lancaster Sound passed out of the Sound over the full range of 33 km along section C-C'.

Eight of the fifteen satellite-tracked drifters released, in the summer of 1978, were deployed within 55 km of the east coast of Devon Island. Of these, seven described intrusive current like patterns while one failed prematurely. In addition, two pairs of drifters were released within 10 km of the southern and northern coastlines of Lancaster Sound at approximately 82° W.

The summer 1978 drifter data is more difficult to interpret: the data quality was lower, in comparison with summer 1979 drifter data, due to reduced positional accuracy. In addition, as a result of the more severe ice conditions encountered in the summer of 1978, a persistent ice-edge was present in eastern Lancaster Sound, stretching from just west of Cape Warrender to N.W. Bylot Island. By late August, the ice to the west of this line had become weak and contained many openings; however, an ice edge remained until early September. Because of the extensive ice coverage for much of the summer of 1978, the drifters were confined to the open water side of the ice-edge. As a result the drifter tracks may deviate from the current pathlines.

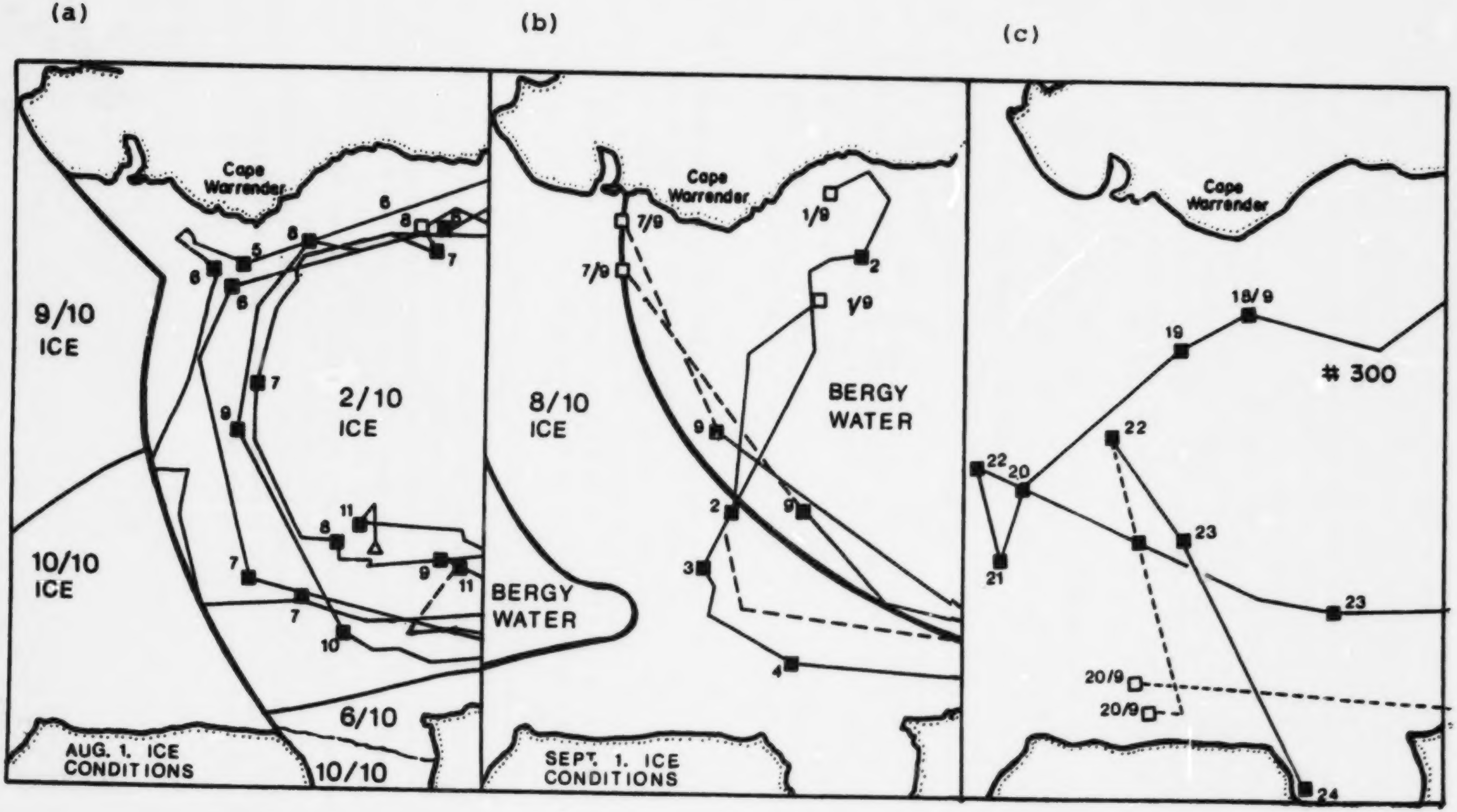

(a)
(b)
(c)
Cape Warrender
9/10 ICE
10/10 ICE
2/10 ICE
6/10
10/10
AUG. 1. ICE CONDITIONS
8/10 ICE
BERGY WATER
SEPT. 1. ICE CONDITIONS
7/9
1/9
# 300
18/9
20/9

Figure 5.2.3-3: Tracks of satellite-track drifters released in 1978. Also shown are the boundaries of the ice pack near the time of the observation.

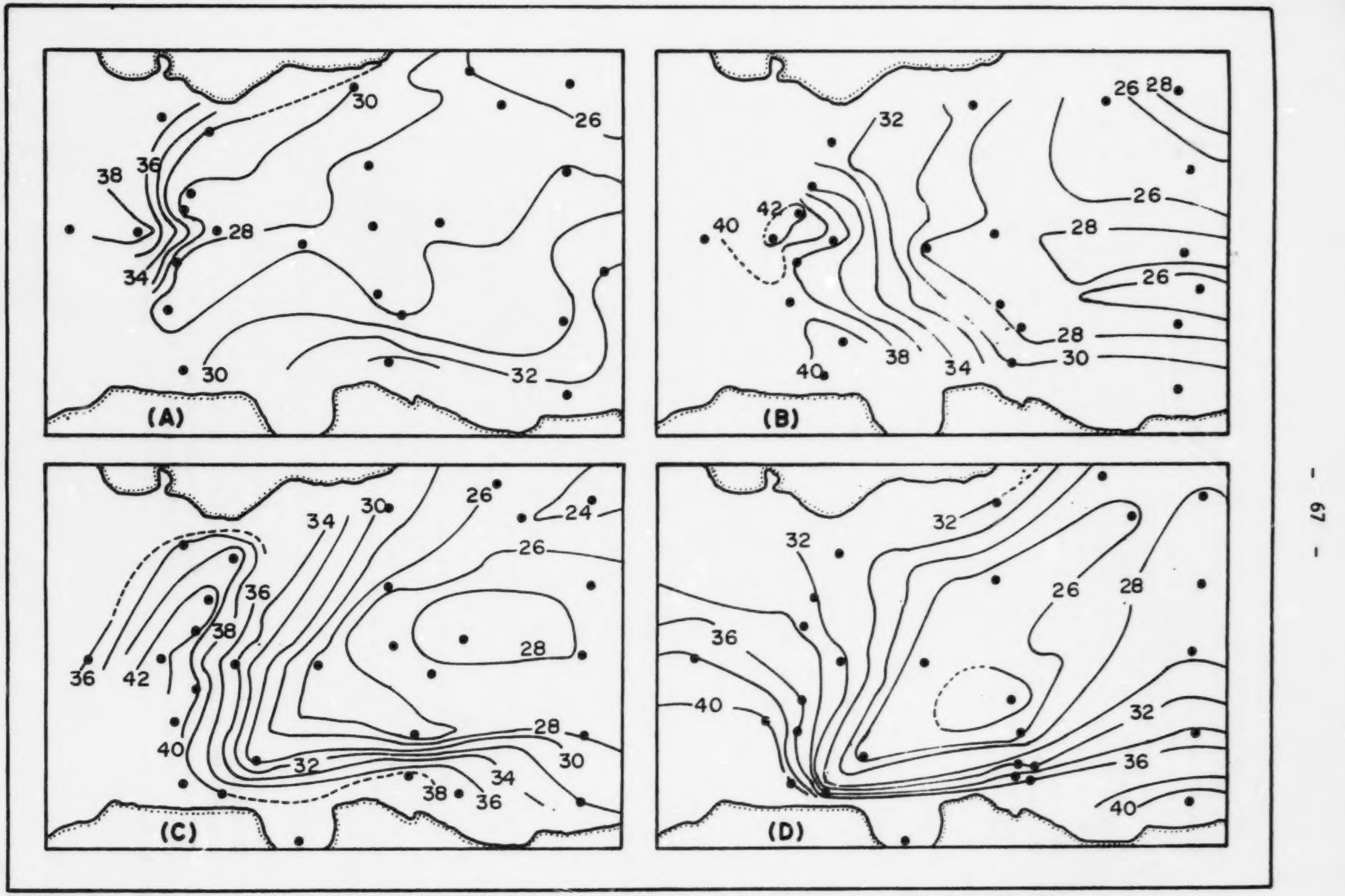

(A)
38
36
34
28
30
26
30
32
(B)
32
26
28
42
40
26
28
26
38
34
28
30
40
(C)
34
30
26
24
26
36
38
28
36
42
40
28
32
34
30
38
36
(D)
32
32
26
28
36
40
32
36
40

Figure 5.2.3-4: Dynamic height anomalies (in dynamic decimeters) relative to 300 dbar level for four periods of CTD observations in 1979: (1) July 18-19, (2) July 29-August 3, (3) September 2-4 and (4) September 14-23.

The drifter tracks of early August are displayed in Figure 5.2.3-3(a) along with the position of the ice edge on August 8 as determined from satellite imagery. The drifter pathlines are similar to the mode (1) pattern of the 1979 drifter data with a penetration into eastern Lancaster Sound of 48 to 62 km at mid-Sound. Further penetration was limited by the presence of the ice-edge, but the measured range is consistent with the penetration of drifters in 1979 when the ice conditions were much less severe and did not limit the westward movement of drifters. This similarity suggests that the position of the ice-edge itself may be related to the presence of the intrusive current although summer ice-edge data from other years has not been examined to test this hypothesis further.

Later in the summer of 1978, the intrusive current carried two drifters released east of Devon Island into eastern Lancaster Sound (Figure 5.2.3-3(b)). Both followed paths that carried them into the region in Southern Lancaster Sound between the envelopes of the mode (1) and mode (2) tracks of 1979 (Figure 5.2.3-1); the presence of ice to the west and the south may have limited further motion within the mode (2) pattern.

The final set of 1978 drifter tracks for the period September 15-25 includes the tracks of two drifters released off the coast of Borden Peninsula. Both drifters moved eastward to exit the sound along northwestern Bylot Island but one (370) first travelled northward to the middle of the Sound and back prior to resuming its net eastward motion. The remaining active drifter (300) was released 55 km east of Philpots Peninsula off Devon Island on August 28. Following a 13 day period of weak southwesterly motion, the drifter entered Lancaster Sound well offshore (30 km), outside of the normal limits of the inflowing intrusive current. It then proceeded to the southwest penetrating 95 km into the Sound off western Borden Peninsula before turning into an anti-cyclonic loop and exiting the Sound. The track is similar to a mode (2) circulation pattern but extends approximately 5 km further west than the outer limit of the mode (2) envelope of 1979 drifter tracks. This track coincides with CTD data of September 19 which suggest a deep penetration of the intrusive current for this period, as discussed below.

Circulation Patterns from the 1978 and 1979 CTD Data

By using the methodology of classical oceanography, the surface circulation can be inferred from the internal mass distribution as determined by CTD profiles. As discussed in section 3.2 this means of studying the circulation is subject to a number of uncertainties; nevertheless, the derived patterns will generally reflect the spatial distribution of strong circulation features.

In Figure 5.2.3-4 (1) to (4), the four periods of synoptic 1979 CTD coverage are presented as maps of surface dynamic height anomalies relative to a 300 decibar reference level. The intrusive current is clearly visible in each map. Its most prominent feature is the cross-Sound flow from north to south; at mid-Sound the intrusive current is located between 25 and 72 km west of the line joining Cape Sherard and Cape Hay. The corresponding observed mid-Sound range from the 1979 drifter data of 35 to 70 km is in excellent agreement considering the 20-25 km spacing between mid-Sound CTD stations. The mid-Sound portion of the flow varies among the four observation periods. On July 18-19, the flow had a southwesterly tendency, heading towards the western end of Borden Peninsula. Later, in early August, the streamlines show a southeasterly set towards N.W. Bylot Island. For the last two sets of CTD observations (September 3-4 and September 14-23), the mid-Sound flow appears to be southerly carrying the water towards central Borden Peninsula whereupon the flow turned abruptly to the east. In terms of the two modes derived from the 1979 drifter data, the first, third and fourth sets of CTD derived circulation patterns follow a mode (2) pattern while the other is a mode (1) pattern.

In the circulation patterns derived from the CTD data, the inflowing and outflowing portions of the intrusive current are not as prominent as in the case of the drifter velocities (Figure 5.2.3-2). This discrepancy is due to the apparent confinement of much of the intrusive current between the shoreline and the innermost CTD station. On the northern side of the Sound, the CTD station nearest the coast (4F) is located 9 km from shore with the next station (4E) being 32 km offshore. Only in the fourth and last CTD circulation map is there evidence of appreciable flows between stations 4E and 4F: if we assume that for the other three synoptic periods, the intrusive current is of comparable magnitude as suggested by the drifter and current meter as well as the mid-Sound CTD derived circulation, it then follows that most of the flow was within 9 km of the Devon Island coast.

Off northwestern Bylot Island, the CTD data suggests that the outflowing current may at times extend further offshore than the inflowing current does on the opposite side of the Sound. On September 2 and September 22, on the basis of the dynamic height anomaly isopleths, much of the outflowing current was located between stations 4A and 4B, located 11 and 23 km from the Bylot Island coast. However, on July 30 the geostrophic flow between 4A and 4B was low; given the considerable cross-Sound flow at that time, we infer that the strong outflow was located within 11 km of the coastline. Using similar reasoning, the half of the outflow not found between station 4A and 4B on July 18 is taken to be inshore of 4A. Thus, the bulk of the outflowing current appears to be located within 23 km of the Bylot Island coastline.

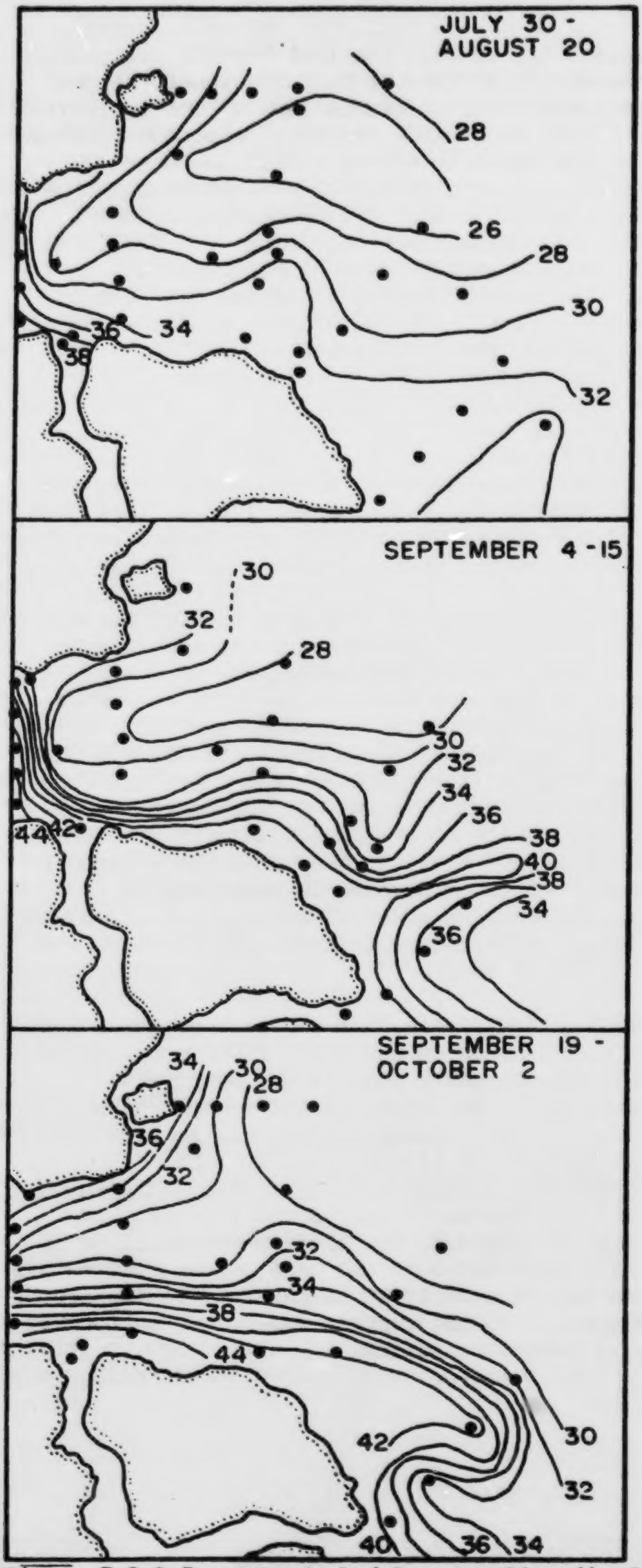

JULY 30 -
AUGUST 20
28
26
28
30
36
34
38
32
SEPTEMBER 4 -15
30
32
28
30
32
34
36
38
40
38
34
36
44
42
SEPTEMBER 19 -
OCTOBER 2
34
30
28
36
32
32
34
38
44
42
30
32
40
36
34

Figure 5.2.3-5: Dynamic height anomalies (in dynamic decimeters relative to 300 dbar level for 1978 CTD observations.

In the summer of 1978, three sets of synoptic CTD casts were collected in eastern Lancaster Sound. The station spacing was less dense with fewer stations west of Navy Board Inlet both along and across the Sound (Figure 5.2.3-5). For the first two sets of 1978 CTD data, the computed surface circulation patterns are similar to that of August 1-2, 1979, and in good agreement with a mode (1) circulation pattern. The latter period of the 1978 dynamic height anomaly streamlines differs significantly from those of any other period of CTD data in both 1978 and 1979. The circulation for this period (September 19 - October 2) shows a deeper penetration into Lancaster Sound, 70 km beyond the Cape Sherard - Cape Hay line. Lacking any CTD stations further to the west, it is not possible to define the extent of the penetration. However a satellite-tracked drifter (300) was observed to penetrate to nearly 90 km in Lancaster Sound on September 21-22 shortly after the collection of the CTD data. Along with the deeper penetration, the contours of dynamic height anomaly suggest that the inflowing and outflowing current was wider, extending further offshore: the inflowing portion was observed out to 30 km from the Devon Island coast while the outflowing current may have extended up to 50 km from the Bylot Island coast.

Current Meter Data: Subsurface Current Distributions

To augment the description of the intrusive current, we examine the subsurface current meter data. Drifter and CTD data provide extensive spatial coverage at long intervals, while the current meters record many measurements at a small number of sites. Aside from the difference in the spatial and temporal nature of the two data types, we must also consider the difference in the depth of the measurements. As discussed in Section 4, the movements of the satellite-tracked drifters are representative of currents from 4 to 11.6 m, while the uppermost current meters were set at a nominal depth of 35 m (the actual mean depths varied from 24 to 80 m). In view of the complex and time varying vertical density structure which is often observed between these measurement depths (Section 5.9) we first compare simultaneous drifter and current meter measurements.

Using the summer 1979 data, velocities of those drifters which passed within 6 km of current meter moorings H, L or M were compared with the simultaneous upper current meter velocity, as shown in Figure 5.2.3-6. While the number of such comparisons is very limited (4 cases for mooring H, 7 cases for mooring L and 2 cases for mooring M), the results provide an indication of the consistency of the two types of near-surface current data. The directions agree remarkably well (to within ± 25 degrees) in view of the differences in spatial and temporal averaging. A larger scatter is found for the comparison of speeds with the ratio of current meter to drifter speeds being 0.6 ± 0.4. The discrepancy between

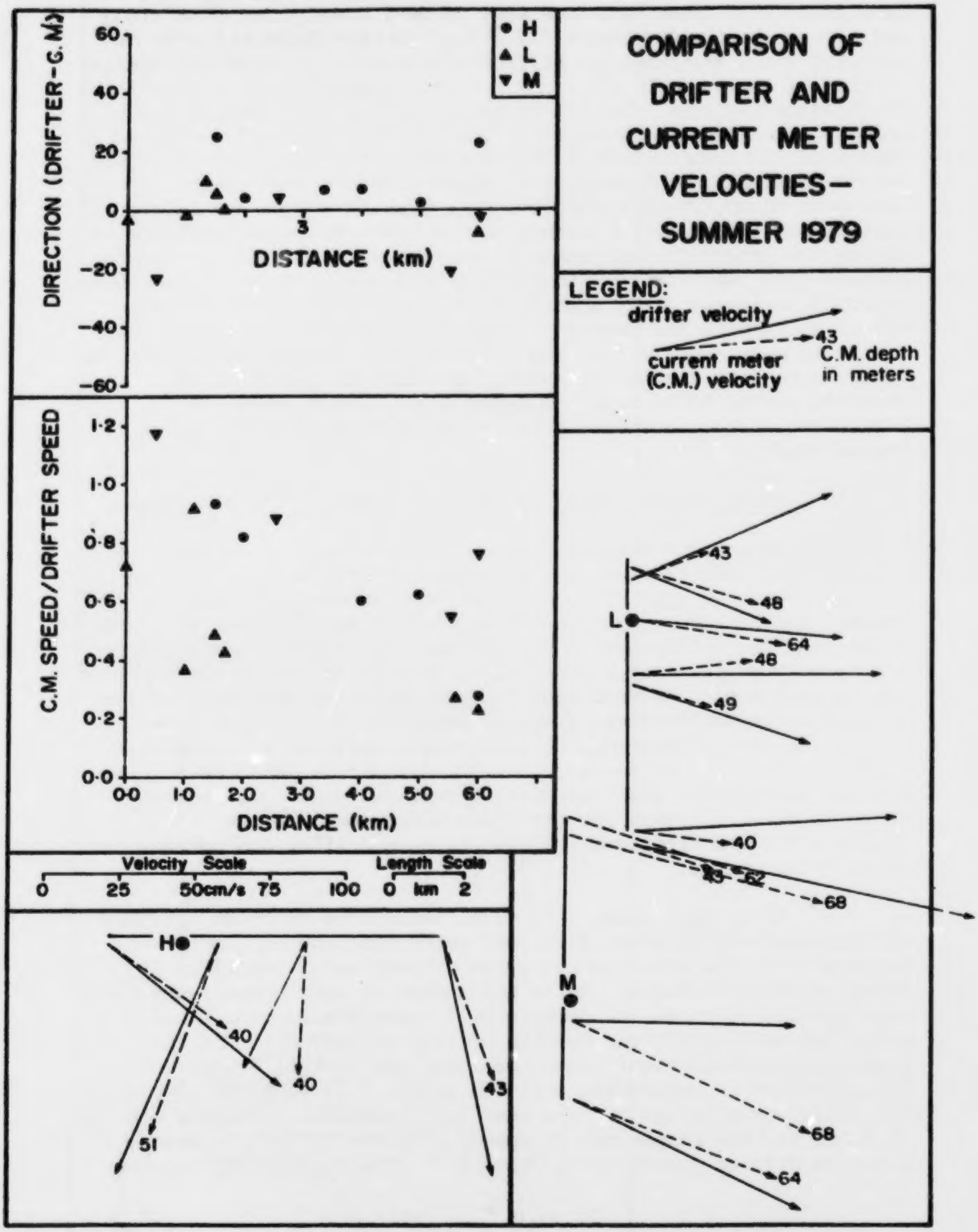


Figure 5.2.3-6: A comparison of drifter and simultaneous uppermost current meter velocities for separations of 6 km or less.

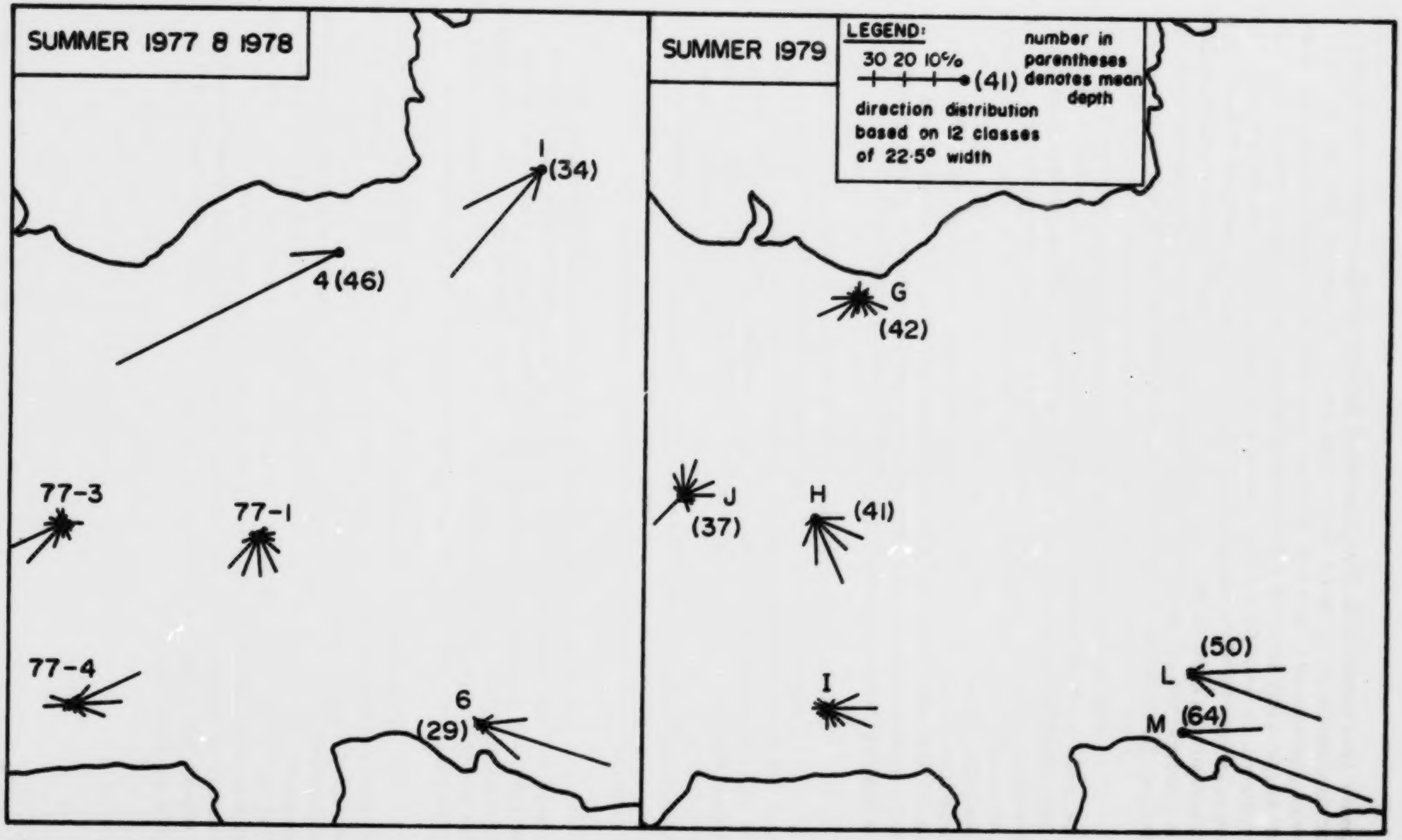

SUMMER 1977 8 1978
I (34)
4 (46)
77-3
77-1
77-4
6 (29)
SUMMER 1979
LEGEND:
30 20 10%
(41)
number in parentheses denotes mean depth
direction distribution based on 12 classes of 22·5° width
G (42)
J (37)
H (41)
I
L (50)
M (64)

Figure 5.2.3-7: Direction distribution of 35 m subsurface currents from 1977, 1978 and 1979 current meter moorings.

speeds increases with the distance between measurement locations; for distances of 3 km or less, the ratio of speeds is 0.65 ± 0.25. These differences between drifter and current meter velocities are not surprising in view of the complexity of the upper zone, as indicated by its density structure (Section 5.9). Based on these comparisons, we will make use of the directional data of the uppermost current meters in describing the near-surface circulation. The current meter speed measurements must be used with more caution bearing in mind the relatively large differences observed.

The directional distribution of currents measured by the uppermost current meters is presented in Figure 5.2.3-7. At mooring sites located in the intrusive current as it flows into and out of Lancaster Sound (stations 1 and 4; 6, L and M), the flow was characterized by low directional variability. The site of the steadiest flows in terms of directional variations was station 4 where the observed range of directions was from 223° to 277° with 95% of the measured currents falling within a 36° range centred on 251°. These results are in good agreement with the description of the nearer surface currents based on the drifter data.

On the opposite side of the Sound, the outflowing easterly current is characterized by relatively steady flows that are somewhat more variable than those on the north side. At station L, 95% of the measured directions were between 60° and 150°, while closer to shore at station M, the directional spread was smaller ranging from 70° to 130° for 95% of the data. Proceeding downstream, the directional variability increases as indicated by the data at stations 6 and 8 where the 95% range of directional variability encompasses 210° and 250°, respectively.

A similar comparison of the subsurface speeds at the levels of the uppermost current meters indicates increased speed variability between the inflowing and outflowing portions of the intrusive current (Table 5.2.3-2). While the mean speeds are lower, the maximum speeds are larger at stations off the northwest coast of Bylot Island than off the southern coast of Devon Island.

From the drifter data, we have previously seen that the greatest variable part of the intrusive current occurs in the course of its crossing Lancaster Sound. The variability is clearly demonstrated in the directional distributions of subsurface currents measured at stations 77-1 and 77-3 in the summer of 1977 (Fissel and Wilton, 1978) and stations H and I in the summer of 1979. The mean speeds here are reduced as compared to other portions of the intrusive current but strong flows are occasionally observed; the largest recorded subsurface current (111.5 cm/s) was measured in 1977 at station 77-3.

Table 5.2.3-2

Summary of current meter measurements from the uppermost current meter at sites located in the intrusive current. Where pressure data is not available, the nominal depth is provided in parenthesis. (The steadiness factor is defined as the vector averaged speed divided by the mean speed times 100 percent (Ramster et. al. 1978). For locations where the steadiness factor is 70% or less the vector averaged mean is not representative of the time series current data).

Station	Record Length	Mean Depth	Speed		Vector Average		Steadiness Factor
			Mean	Max.	Speed	Dir.	B
	(days)	(m)	(cm/s)		(cm/s)	(°T)	(%)
77-1	60	(35)	24.3	95.4	16.2	177	67
77-3	63	(35)	37.4	111.5	19.0	233	51
1	45	35	21.4	73.7	20.3	230	95
4	20	46	58.2	89.4	57.6	251	99
6	46	29	50.5	104.3	45.3	110	90
8	45	83	27.0	90.0	20.6	96	76
G	61	42	21.1	78.2	6.8	208	32
H	52	41	33.8	84.9	26.7	154	79
I	52	(35)	20.6	75.1	6.6	134	32
J	50	37	21.5	79.6	9.0	25	42
L	56	50	36.1	86.3	34.3	105	95
M	55	64	52.0	104.5	51.1	105	98

Previously, on the basis of drifter data, the intrusive current was described as following two distinct spatial patterns in the middle of the Sound: the first has velocities directed to the south-east and the second has velocities of south to southwesterly (Figure 5.2.3-1). Stations 77-3 and H, occupied in 1977 and 1979 respectively, are located within 1.3 km of each other within the envelope of southwesterly drifter pathlines and just on the outer flank of the southeasterly drifter pathlines. The directional distributions for both these stations are characterized by southwesterly and southeasterly flows respectively: In 1977, 75% of the currents had a southerly component while the corresponding figure for 1979 was 95%. However, the directional distributions are not bi-modal but rather indicate a continuum of directions from southwesterly to southeasterly. This is not incompatible with the drifter velocity data which exhibited a considerable amount of smaller scale variations superimposed on the lower frequency net motions. These smaller scale phenomena, largely of tidal and inertial origin, will tend to broaden the directional distributions. As well, the core of the intrusive current may be relatively narrow in relation to the envelope of drifter pathlines. At times when the major intrusive current flows are away from the mooring site, the current meter data reflects more small scale local currents rather than the intrusive current. Again, this will broaden the directional distribution of currents as measured at any one site. However, the bi-modal nature of the intrusive flow can be detected by examining the directional distribution of those current measurements whose speeds are sufficiently large to be identified with the presence of the intrusive current. For example, the joint speed-direction distribution, for station H, reveals that for those currents with speeds greater than 48 cm/s, the directional distribution had two peaks at 165 degrees and 205 degrees.

Circulation off Borden Peninsula

The description of the intrusive current presented above has concentrated on the inflow on the north side of the Sound, the southward movement at mid-Sound, and the outflow off northwestern Bylot Island. In the waters off Borden Peninsula extending to the middle of the Sound, particularly complicated and variable circulation patterns have been observed. Because of this complexity, the data sampling in this area must be more intense to provide a complete description of the surface circulation of this region. We must necessarily restrict our description of the major circulation features to those periods when the simultaneous drifter and current meter data is sufficiently detailed.

It is likely that the complexity results from the fact that the intrusive current meets the outflowing current of Lancaster Sound in this region. There is evidence that the intrusive current does not always extend into this region. At times, the intrusion passes from mid-Sound directly to the area off northwestern Bylot Island bypassing the Borden Peninsula offshore region (referred to as mode (1) earlier). For the remaining periods it proceeds south to southwestwards from mid-Sound approaching to within 15 km of Borden Peninsula (mode 2). The eastern outflow of water from western Lancaster Sound has been observed in the 1979 drifter data (Section 5.2.7) and historical data (Section 3). It tends to be concentrated on the southern side of the Sound and forms part of the net flow of Arctic Ocean water into Baffin Bay through the Arctic Islands. The temporal variations of this current are not well understood; there is some evidence of important variations in the outflow of Arctic Water further west in Crozier Strait over periods of several weeks as well as a strong annual variation with maximum flows in winter (Greisman and Lake, 1978). Considering that the region off Borden Peninsula is the junction of these two intense flows, which vary both in time and space, the complex circulation patterns of the area are not surprising.

In Figure 5.2.3-8, simultaneous 1979 drifter and upper current meter data are assembled for three cases of mode (1) intrusive flow. In this mode the area of immediate interest is located to the west of the intrusive current. In two cases, August 16 and August 26, the flows are relatively weak (20 cm/s) at both stations I and J, while at station H the flow is stronger and depends on the proximity of the intrusive current. At other times stronger and more complicated flow patterns are found to the west of a mode (1) intrusive flow. For example, from September 24-30, two drifters travelled west to east through Lancaster Sound while three other drifters described the mode (1) intrusive pattern. One of the easterly moving drifters (1961) located within 10 km of the Borden Peninsula coastline moved easterly at 25 cm/s. The other (1971), travelling through the middle of the Sound three days later, was moving quickly with an easterly velocity of 85 cm/s. Easterly movements at mid-Sound west of the mode (1) intrusive flow were also observed on September 8-10 (Figure 5.2.3-10c) accompanied by a strong westerly flow at station I. This case is discussed in more detail below.

The easterly movements, as measured by upper current meters at station H and J, persisted until September 17 but no drifters were in the area of the intrusive current to determine if the mode (1) pattern continued over this period. However, two drifters approached the region off Borden Peninsula from the west on September 14-15: the track of one drifter (1951) travelling along the middle of the Sound described a 23 km diameter anti-cyclonic loop before proceeding southeasterly to northwest Bylot Island (Figure 5.2.3-9(a)). This track implies that the intrusive current is of mode (1) type and located further to the east along the Borden Peninsula coastline. As the first drifter entered its loop the current off the Borden Peninsula reversed as indicated by the upper current measurements at station I and the reversal of the eastward

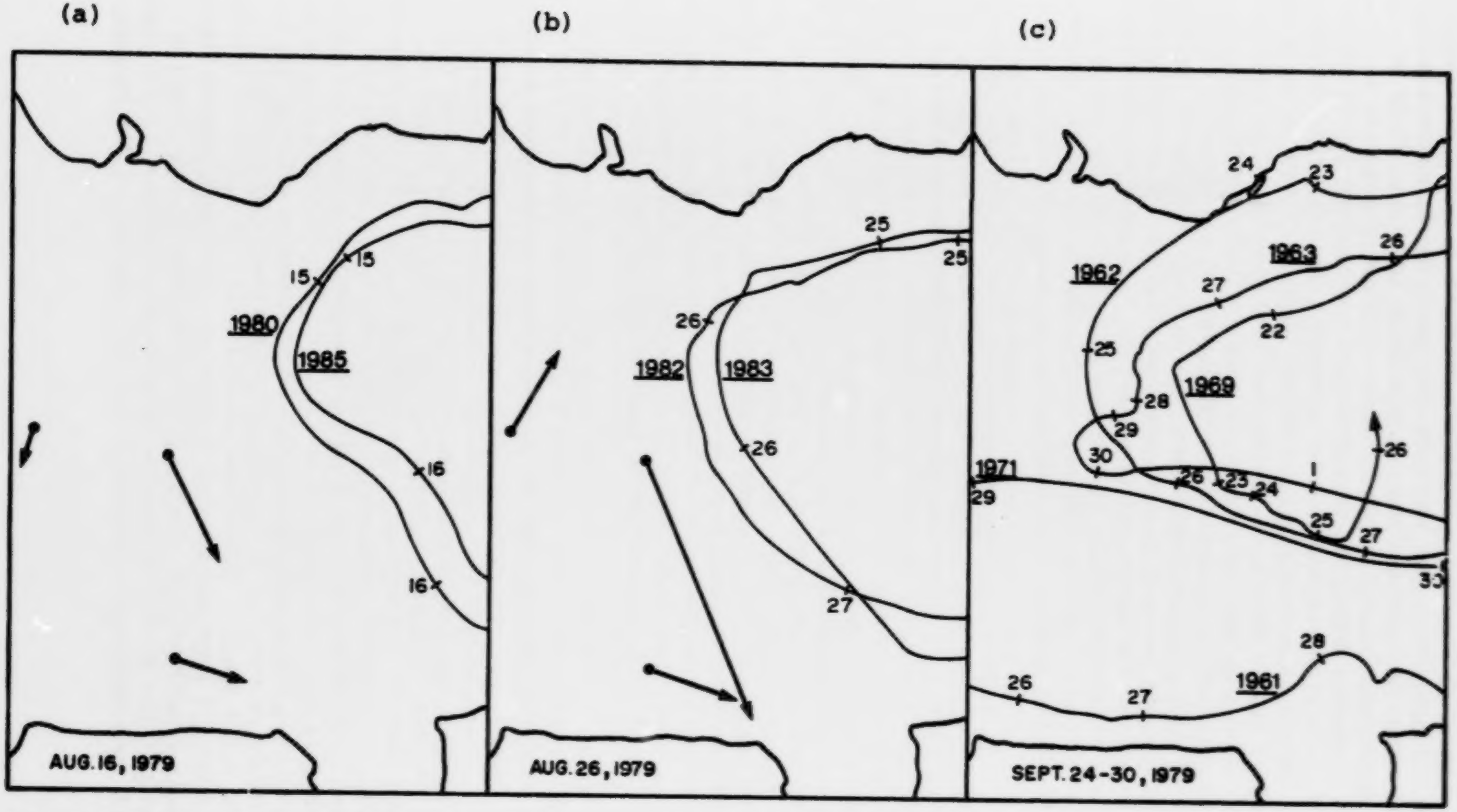

(a)
(b)
(c)
1980
1985
15
15
16
16
AUG.16, 1979
1982
1983
25
25
26
26
27
AUG.26, 1979
1962
1963
1969
1971
1961
24
23
26
27
22
25
28
29
30
26
23
24
1
26
25
27
33
29
28
26
27
SEPT. 24-30, 1979

Figure 5.2.3-8: Case studies of simultaneous 1979 drifter and upper current meter velocities suggesting a mode (1) intrusive current pattern.

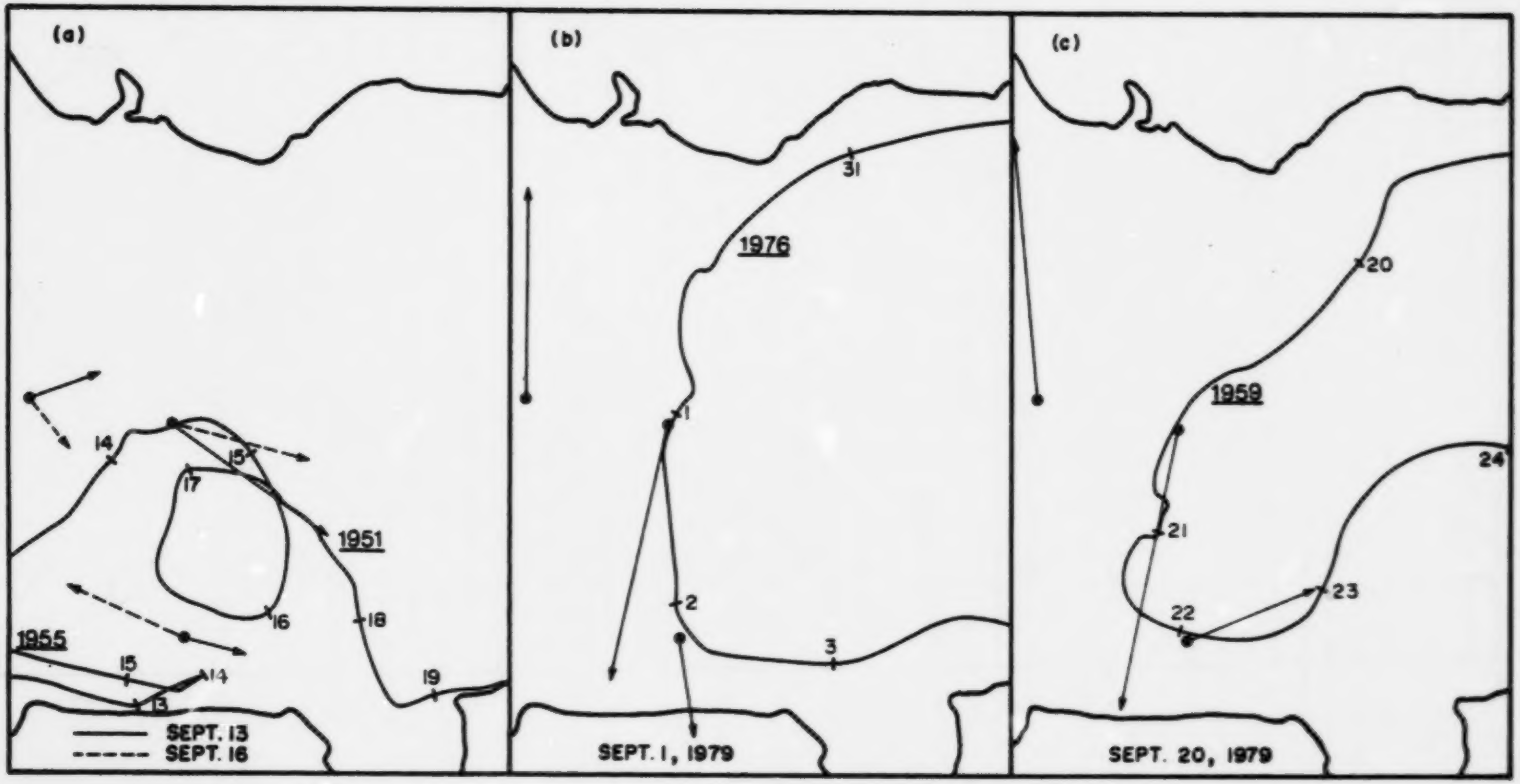

(a)
(b)
(c)
1955
15
13
14
SEPT. 13
SEPT. 16
14
15
17
16
18
19
1951
1976
31
1
2
3
SEPT. 1, 1979
1959
20
21
22
23
24
SEPT. 20, 1979

Figure 5.2.3-9: Case studies of simultaneous 1979 drifter and upper current meter velocities illustrating (a) anti-cyclonic gyre motions off Borden Peninsula, (b) and (c) mode (2) intrusive current patterns.

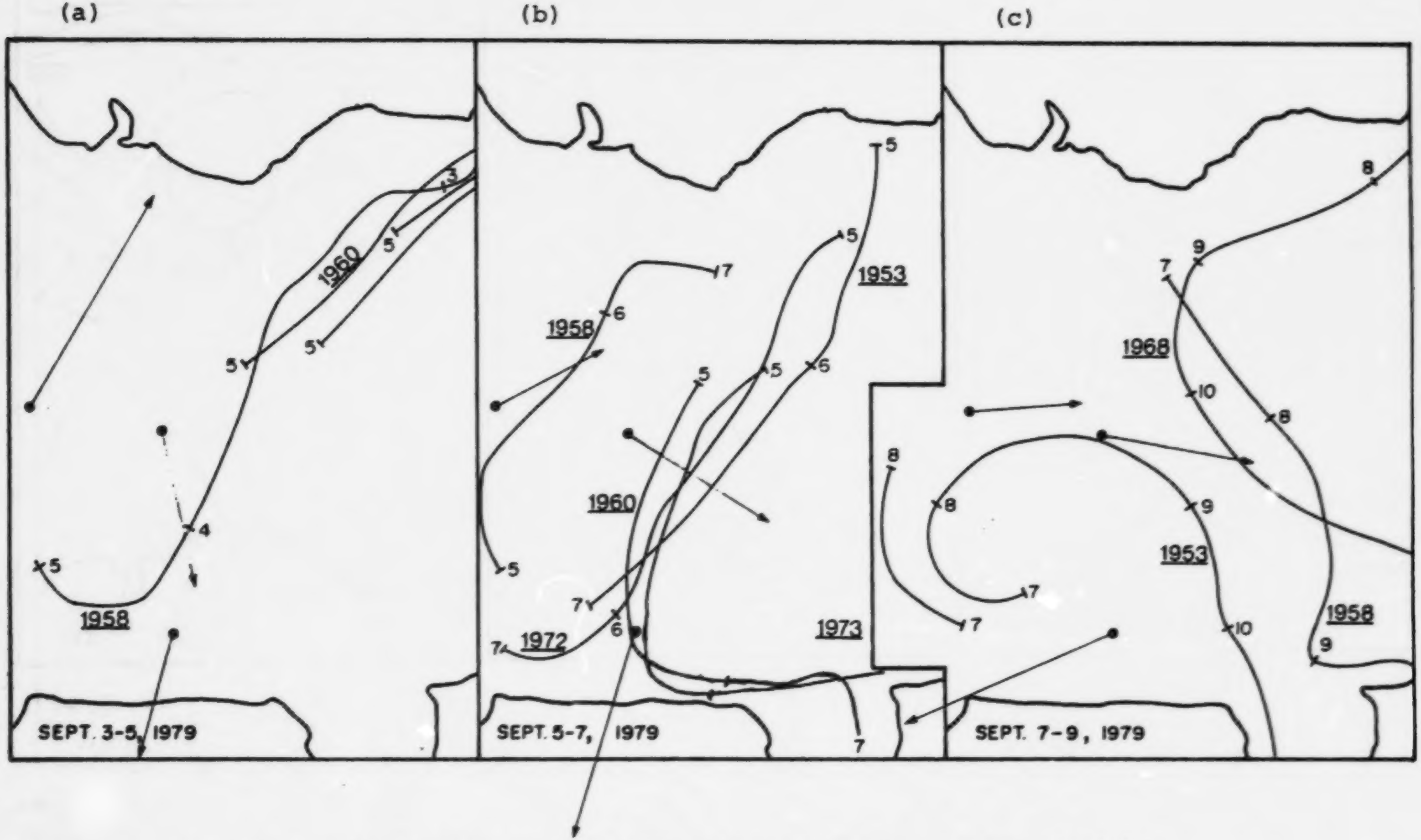

(a)
(b)
(c)
1960
1958
3
5
5
5
4
5
SEPT. 3-5, 1979
1958
1953
1960
1972
1973
7
6
5
5
5
5
6
7
7
6
5
7
SEPT. 5-7, 1979
1968
1953
1958
8
9
7
10
8
8
8
9
7
7
10
9
SEPT. 7-9, 1979

Figure 5.2.3-10: Case studies of simultaneous 1979 drifter and current meter velocities from September 3 to September 9, illustrating transition from mode (1) to mode (2) pattern of intrusive current.

movements of drifter 1955. At times of mode (1) intrusive currents, both easterly and westerly coastal currents have been observed off Borden Peninsula. In mid-Sound the flows appear to be more consistently directed towards the east.

During mode (2) patterns of the intrusive current, the current enters the Borden Peninsula region and turns either east or west within 20 km of shore. At Station J, in mid-Sound, and to the west of the intrusive flows, the current had a strong northerly component on the three occasions of mode (2) intrusive flow as determined by 1979 drifter data (Figure 5.2.3-9(b) and (c), 5.2.3-10(a)). The reason for this is not known; it may reflect a pronounced northward deflection of the eastward flowing Lancaster Sound current by the penetration of the intrusive current into the Borden Peninsula area. However, this is only speculation and cannot be confirmed without simultaneous measurements of the Lancaster Sound outflow and the mode (2) intrusive current.

A most interesting event occurred from September 4-8 off Borden Peninsula. For a week or more prior to this period, the intrusive current had been following mode (2) with the currents turning east on approaching Borden Peninsula. On September 4, one drifter (1958) turned west rather than east. Over the next two days two other drifters (1953 and 1972) followed the same westerly course while two others (1960 and 1973) turned east (Figure 5.2.3-10). The drifters which had moved to the west, then turned north and continued to turn, describing an anti-cyclonic loop. Because one drifter (1972) failed on the northward turn, only two loops were described with one (1958) being elongated to the north having dimensions of 50 x 20 km while the other was more nearly circular, having a diameter of 25 km. Upon completing the loops both drifters headed south towards Navy Board Inlet with one entering the Inlet and the other moving east along the coast of Bylot Island. Following the onset of this anti-cyclonic circulation to the west of the intrusive flow, the currents at mid-Sound (stations H and J) rotated so that they were aligned in an easterly direction. Concurrently with this, the currents at station I off Borden Peninsula veered from southerly to westerly and strengthened. By September 8, the intrusive current had reverted to the pattern of mode (1) as indicated by the track of drifter 1968. This pattern was likely maintained over the next 9 days (Figure 5.2.3-9(a)). Thus, the onset of westerly motion off Borden Peninsula from the mode (2) intrusive pattern appears to have been related to the formation of an anti-cyclonic gyre which in turn coincided with a change of the intrusive current from mode (2) to mode (1). This course of events is not unexpected since the pathlines of the drifters which turned west crossed their previous tracks 2 to 3 days later heading southeast rather than southwest. Such a flow pattern must be transient in nature.

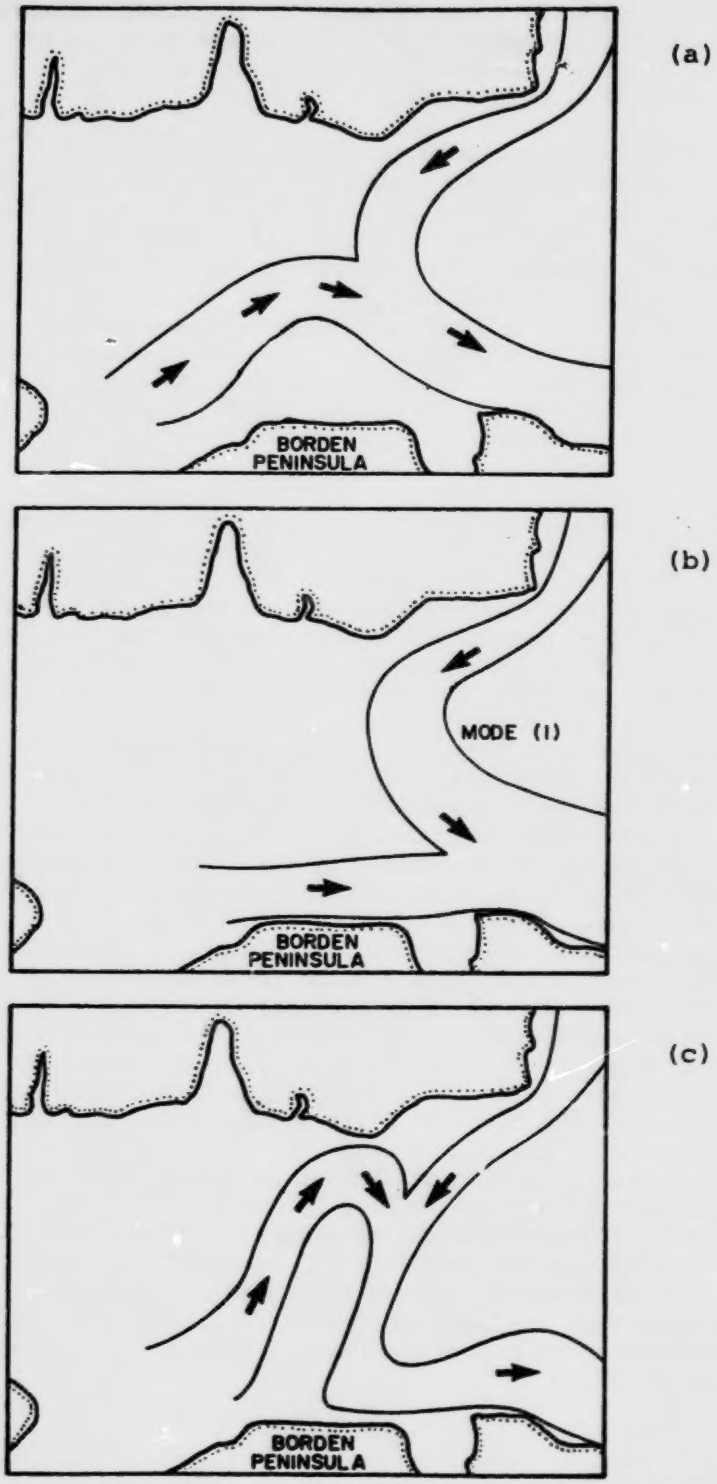

(a)
BORDEN PENINSULA
(b)
MODE (I)
BORDEN PENINSULA
(c)
BORDEN PENINSULA

Figure 5.2.3-11: Schematic representation of repeated circulation patterns in eastern Lancaster Sound.

The patterns of circulation immediately to the west of the intrusive current were found to have small spatial scales of 20 km, and varied significantly in time (based on the 1979 drifter and current meter data). On two occasions, anti-cyclonic gyres were observed off Borden Peninsula (Figure 5.2.3-11(a)). The fact that similar circulation features have been observed in other years (1960, 1961) in maps of surface dynamic heights (section 5.8) lends more credibility to the existence and persistence of these anti-cyclonic gyres. At other times however (September 26-28; October 4-5, 1979), eastward movements were observed along Borden Peninsula within 15 km of the coast (Figure 5.2.3-11(b)). Such movements are inconsistent with the presence of the anti-cyclonic gyre which would result in westerly currents along the Borden Peninsula coastal area. Yet another circulation pattern was a large loop in the eastward movement of Lancaster Sound water moving northward across the middle of the Sound 20-40 km to the west of the intrusive current (Figure 5.2.3-11(c)). On the two occasions when this feature was observed, the intrusive current was in mode (2). These types of circulation patterns, as illustrated in Figure 5.2.3-11, represent three possible patterns of flow at the junction between eastward moving Lancaster Sound outflow water and the intrusive current. This list is by no means complete; other patterns may be possible. As well, the frequency of occurrence of each type of pattern is unknown. Only further field studies including a more detailed array of measurements in the area off Borden Peninsula will provide a more exact description of this complex oceanographic region.

Temporal Variations

The intrusive current in eastern Lancaster Sound is characterized by variations in time as well as the spatial variations described above. From the 1978, 1979 and historical data, the current appears to be a permanent feature of the summer and early autumn circulation. All of the data collected for this study are consistent with an intrusive flow into and out of eastern Lancaster Sound. With the exception of data from one summer (1954), the historical data support this contention (section 5.8). The data of the exceptional year, 1954, is not entirely inconsistent with an intrusive flow but its spatial pattern would have to be somewhat altered (see section 5.8 for further discussion).

Accepting the existence of the intrusive current as a permanent part of the circulation, its properties nevertheless can vary with time. In the preceding part of this section, two different spatial patterns of the intrusive current have been identified from the summer 1979 data. In Table 5.2.3-3, we summarize the mode of the intrusive current for periods when the observational data is sufficient to resolve one pattern or the other. There are many periods where the data is not sufficient to determine which mode the intrusive current followed or even if it had assumed a different pattern altogether. However, a study of mode type in those periods in which the pattern could be resolved (Figure 5.2.3-12) suggests that the persistence of one mode pattern could be as short as two days. The upper bound of persistency based on the summer 1979 data, could extend to 40 days based on the period from July 23 - August 30 in which only mode (1) patterns were observed; of course, mode (2) patterns could have occurred in the several gaps within this period.

Table 5.2.3-3

A listing of the mode of the intrusive current for various periods in the summer 1979. The two modes are defined in the text and illustrated in Figure 5.2.3-1.

Period	Mode	Data Source
July 18-22	(2)	CTD - Figure 5.2.3-4(a)
August 1-2	(1)	CTD - Figure 5.2.3-4(b)
August 15-16	(1)	CM & Drifters - Figure 5.2.3-8(a)
August 18-19	(1)	CM & Drifters
August 25-26	(1)	CM & Drifters - Figure 5.2.3-8(b)
August 31-September 4	(2)	CM & Drifters - Figure 5.2.3-9(b) CTD - Figure 5.2.3-4(c)
September 5-7	(2)	CM & Drifters - Figure 5.2.3-10(b)
September 7-10	(1)	CM & Drifters - Figure 5.2.3-10(c)
September 20-22	(2)	CM & Drifters - Figure 5.2.3-9(c) CTD - Figure 5.2.3-4(d)
September 24-27	(1)	Drifters - Figure 5.2.3-8(c)

Estimates of the persistence of the intrusive current can be made from the current meter time series data. Perhaps the most useful set of measurements for this purpose is that of Fissel and Wilton (1978). From the upper current meter data at mooring stations 77-1 and 77-3 located in the middle of Lancaster Sound in the summer of 1977 (Figure 5.2.3-7(a)), strong flows with a southerly component were measured alternately at either site. The locations are consistent with these moorings being located in either branch of the two modes of the intrusive current; thus, as the flow at one site increases, the flow at the other decreases due to the shift in the location of the intrusive current. After low pass filtering to remove diurnal and higher frequencies, the upper current meter data from stations 77-1 and 77-3 are displayed in Figure 5.2.3-13. Following installation, strong southwesterly currents were measured at 77-3 (mode 2) for 16 days, followed by southerly currents at 77-1 (mode 1) for 19 days. After this, the southwesterly flows resumed at 77-3 for 7 days followed by 5 days of southeasterly flows at 77-1 and then 10 days of southwesterly to southeasterly flows at 77-3. On the basis of these currents the duration of each apparent mode ranged from 5 to 19 days about a median value of 10 days. These estimates of duration of the intrusive current modes fall within the bounds suggested from Figure 5.2.3-12 of 2 to 40 days.

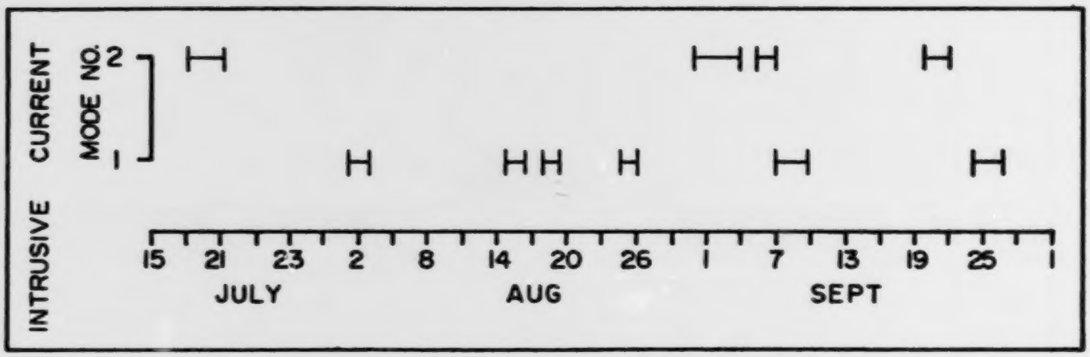


Figure 5.2.3-12

Temporal variations of currents in the region of the intrusive current can be examined further by computing the auto-spectra from the uppermost current meter time series. Using a Fast Fourier Transform Algorithm (Singleton, 1969), the raw spectral values were computed and band-averaged using 10 degrees of freedom to improve statistical reliability. The auto-spectra are displayed in Figure 5.2.3-14 for frequencies up to 0.9 cycles per day (the higher frequency tidal variations and inertial oscillations are discussed in Sections 5.4 and 5.5). For mooring 77-1, 77-3, H, I and J, all located in or immediately adjacent to the portion of the intrusive current crossing Lancaster Sound, the auto-spectra are characterized by increasing variance as the frequency decreases. At

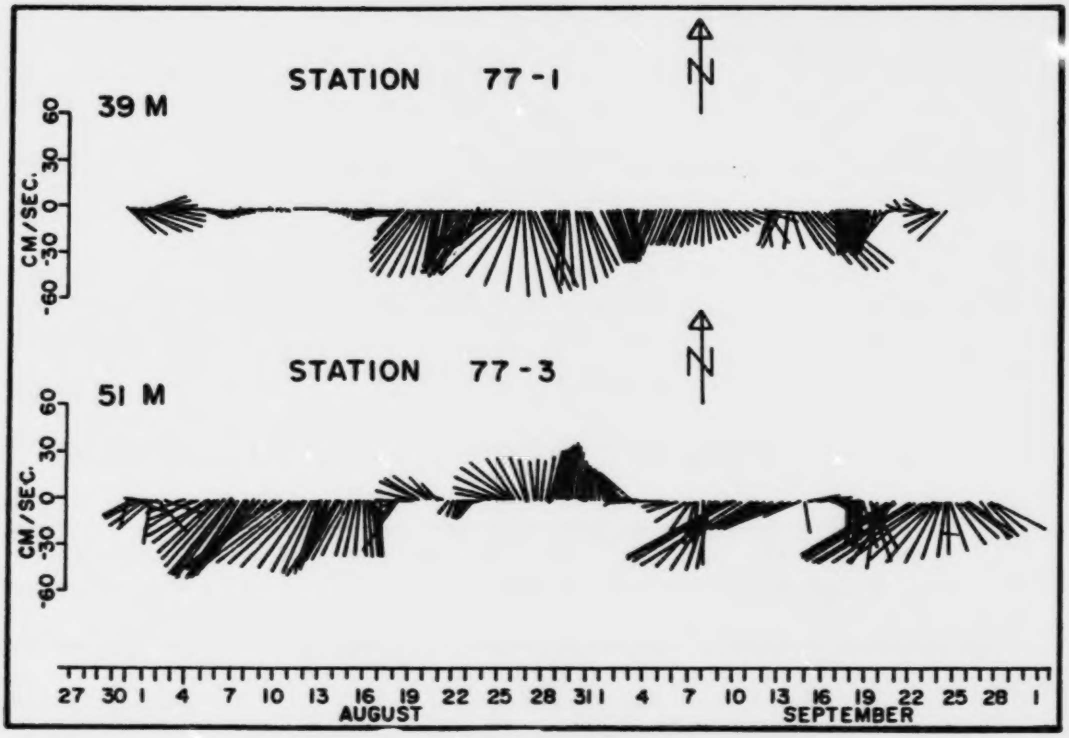


Figure 5.2.3-13: Low pass filtered currents measured at stations 77-1 and 77-3 by the uppermost current meters.

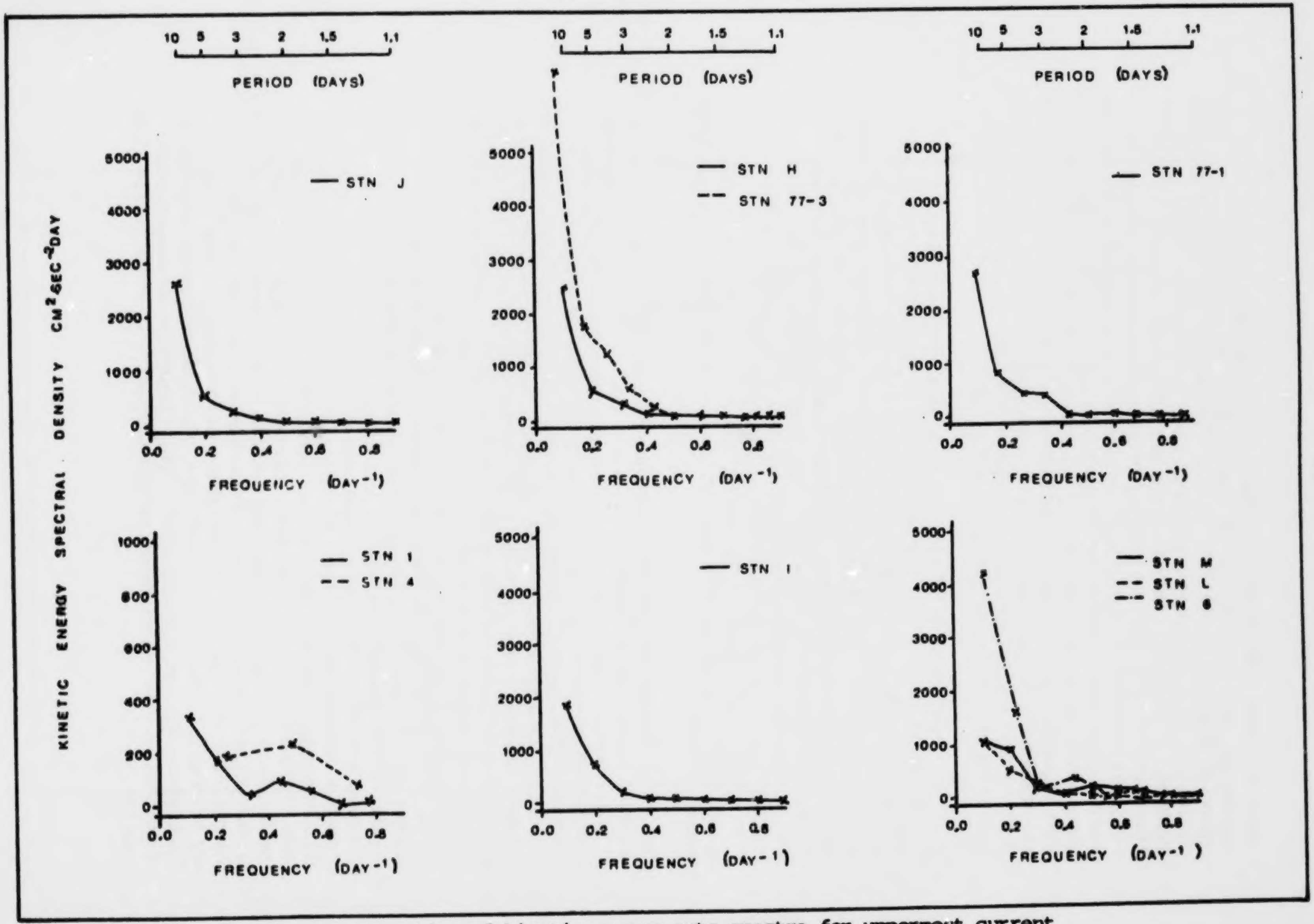


Figure 5.2.3-14: Low frequency portion of kinetic energy auto-spectra for uppermost current meter time series at locations in eastern Lancaster Sound. Each spectral band has 10 degrees of freedom.

every station, 57% or more of the variance between 0.01 and 0.9 cycles per day is found in the lowest smoothed spectral band spanning frequencies of 0.01 to 0.11 cycles per day centred on 0.06 cycles per day (containing periodicities ranging from 9 to 100 days centred on 17 days). Based on the shifts in the location of the intrusive current and the related circulation patterns off Borden Peninsula discussed previously, many of the low frequency variations result from such changes in the spatial patterns. For example, a sinusoidal variation with peak-to-peak amplitude of 50 cm/s, roughly that expected of the core of the intrusive current at the depth of the uppermost current meter, would result in a spectral density of 3125 $(cm/s)^2$ which compares favourably with the lowest frequency levels in mid-Lancaster Sound in 1979.

Spectra from current meter records located in the inflowing portion of the intrusive current (Stations 1 and 4) are characterized by much lower levels and relatively less activity at the lowest frequencies. The sharply reduced spectral levels, down by a factor of 10 from those observed in mid-Sound, reflect the much steadier flows of this part of the intrusive current. From the drifter data there is no evidence of large spatial shifts in the entire current in this region; rather the flows appear to be concentrated in a relatively narrow band with very little directional variability. The variations of the current, largely in speed, appear to occur over a wider range and generally smaller time scales.

The spectra of the uppermost current meters at stations L and M, located off northwestern Bylot Island in the strong outflows from Lancaster Sound, are intermediate between those at stations located in mid-Sound and the inflowing portions of the intrusive current. The spectral levels are larger than those of the inflowing currents, but appreciable spectral levels occur at periods as low as 2 days. However, the currents measured at station 6 in 1978 differ markedly from those at nearby station M in 1979. Separated by only 5.5 km, the spectral level of the lowest frequency band is four times greater than that at station M; while 63% of the low frequency variance is contained in the lowest band at station 6, the proportion for station M is only 36%. These differences could result from a change between the summers of 1978 and 1979; however, the mean and vector averaged speeds agree to within 10%. Another possible explanation is that the variability at the two locations differs significantly. This is not inconceivable since both are located closer to shore than their distance of separation. As well, station M is located off the steep cliffs of northwestern Bylot Island while station 6 is located downstream past the bay separating the cliffs from Cape Hay. Given these differences in location, it may be possible that local conditions could alter the variability of the current between the two sites. Only simultaneous measurements at both sites over an extended period (50-60 days) would settle this question.

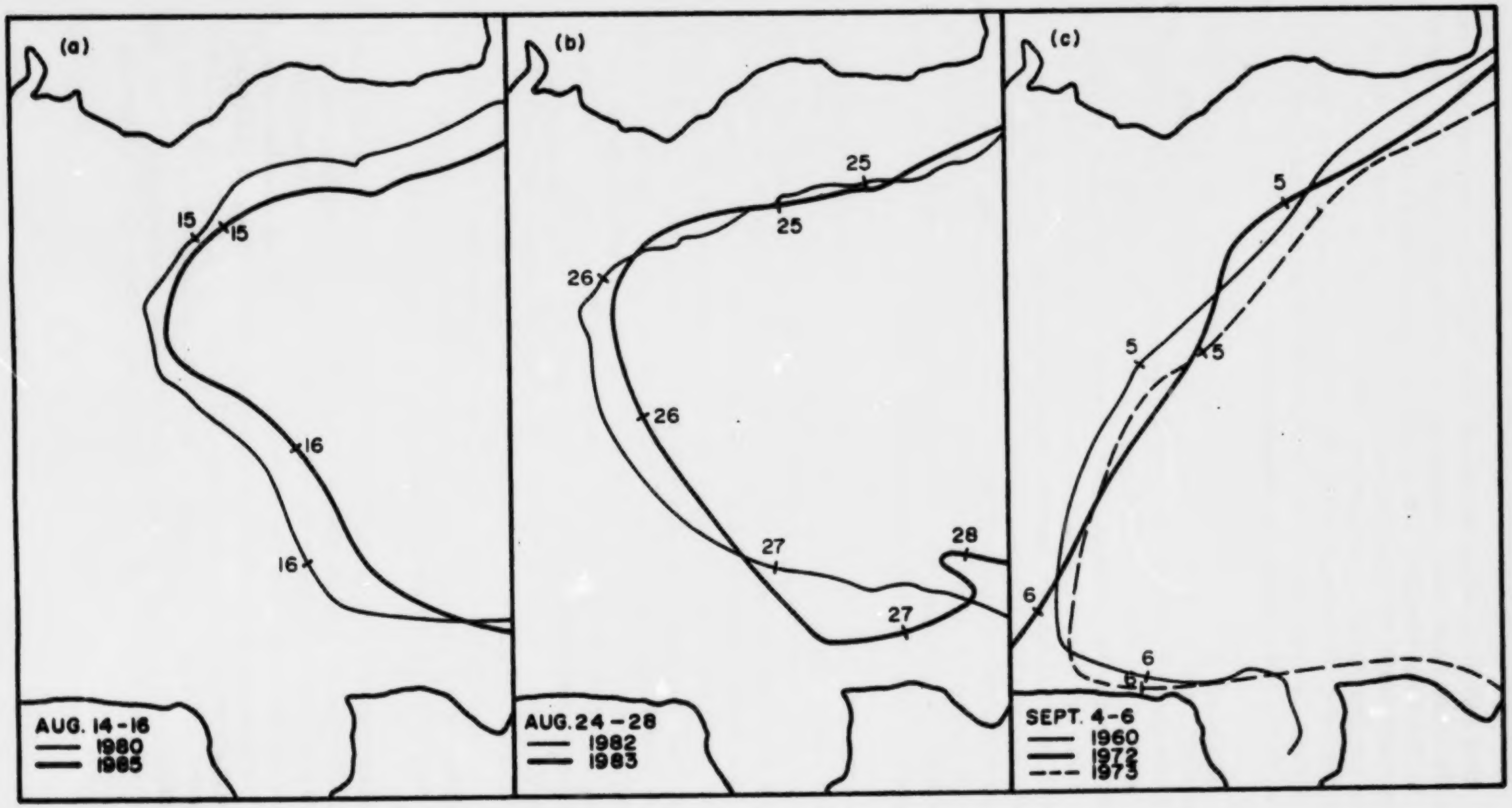

(a)
15
15
16
16
AUG. 14-16
1980
1965
(b)
25
25
26
26
27
27
28
AUG. 24 - 28
1982
1983
(c)
5
5
5
6
6
6
SEPT. 4-6
1960
1972
1973

Figure 5.2.3-15: Simultaneous tracks of 1979 drifters.

Width of the Intrusive Current

The instantaneous width of the intrusive current may be considerably less than that suggested from Figure 5.2.3-7. Based on the 1979 drifter movements, the width of the envelope of drifter tracks for each mode of the intrusive current is about 10 km on the north side of the Sound, increasing to 15 to 25 km as it crosses the Sound and further increases up to 40 km in the outflowing sections. However, direct measurements of instantaneous widths are only possible with a dense array of measurements.

Evidence that the instantaneous width of the intrusive current may be less than the composite of all drifter tracks observed through the summer of 1979 is provided from simultaneous (within one day) tracks of drifters as shown in Figure 5.2.3-15. For the three periods of data, the cross-flow separation between the tracks is 7 km or less in the inflowing and cross-Sound portions of the current, with somewhat larger separations of 10 km in the outflowing region. Of course, these data do not define the full instantaneous width of the current; nevertheless, the fact that the simultaneous tracks follow one another so closely in comparison with the full range of tracks over the season suggests that the instantaneous width may be considerably less.

From the current meter data of 1977 (Fissel and Wilton, 1978), discussed above, the mid-Sound width of the intrusive current is less than the station separation of 32 km. The range of 1979 drifter track cross-sections (Figure 5.2.3-2) provides a similar value for the upper bound of the actual current width. The circulation derived from CTD data is of limited value in defining the current width since the station spacing is approximately 32 km. In three of the four cases of 1979 CTD data, the intrusive current was centred on station 6D as defined by dynamic height anomaly differences at stations 6C and 6E, separated by 45 km. The flow itself may have been considerably narrower but this could not be detected with the station spacing. For one observation period, July 18-22 the intrusive current was concentrated between station pairs 6C and 6D, separated by 23 km and 6C and 5E separated by 14 km. For this one observation period, the instantaneous width of the intrusive current was 14 km or less.

Two current meter moorings, M and L, were located 4 and 15 km from the coastline in the portion of outflowing current from Lancaster Sound off northwest Bylot Island. At both sites the currents were almost always directed to the east by south-east. In the lowest frequency band the currents are negatively correlated with a significant coherence at the 95% level and a phase difference of 200 degrees (Figure 5.2.3-16). In other relatively energetic frequency bands, the coherence levels are not significant with the result that the significance of the overall cross-correlation is

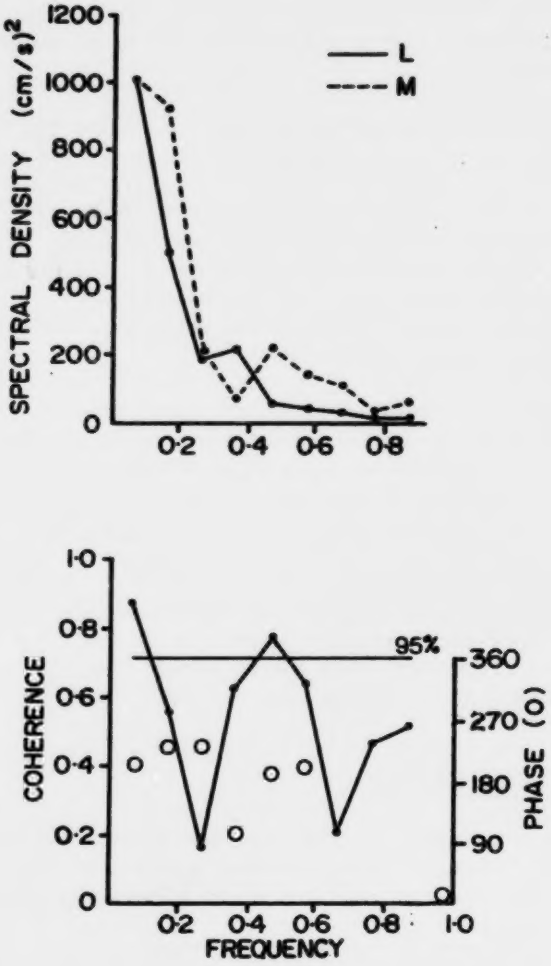


Figure 5.2.3-16: Auto-and cross-spectral values for uppermost current meter data at stations L and M located off northwestern Bylot Island. The 95% significant level for coherence values is shown.

marginal. Such a limited correlation over a distance of just 11 km indicates that while an outflowing current occurs simultaneously at both sites, the temporal variations are not simply related. One possible explanation for the low correlation is that it may reflect a more complex circulation of the outflowing currents due to the junction of the intrusive current with a possible outflow of water from western Lancaster Sound.

The CTD derived circulation patterns indicate that the outflowing current is concentrated on the shoreward side of station 4C, located 23 km off N.W. Bylot Island. On one occasion, July 29 to 30, the outflow appears to be concentrated to the inshore side of station 4A located 8 km from the coast with weak flows further offshore. From the next set of CTD data on September 2, the core of the outflowing currents appeared between stations 4A and 4B, separated by 12 km; however, we cannot rule out significant easterly outflows between 4A and the coast at this time.

To summarize, the instantaneous width of the intrusive current appears to be 10 km or less for the inflowing portion, as determined by drifter data. In mid-Sound, an upper bound as low as 15 km was observed although at other times we cannot confine the width to less than 30 km. The outflowing portion of the current may be more complicated. Simultaneous outflows over distances of up to 23 km offshore have been observed from the CTD data with drifter movements out to 33 km from the coast; little correlation is found for variations of the flow over distances as short as 11 km. Thus, the width of the intrusive current may vary as it moves through Lancaster Sound with a tendency to increase, particularly in the outflowing portion.

Depth of the Intrusive Current

The intrusive current spans a considerable range of depths encompassing all of the Arctic Water layer and the upper portion of the Atlantic Water layer. For the inflowing and outflowing portions of the intrusive current, the vertical profile of the average currents along the mean flow direction is displayed in Figure 5.2.3-17. Because the intrusive current appears to be present throughout the period of observations, the mean vertical profile from the current meter data is expected to be representative of the intrusive current itself. For estimates of the range of flows associated with the major current, a low pass digital filter was applied to the time series data to remove diurnal and higher frequencies; the minimum and maximum component of the current along the major axis is displayed in Figure 5.2.3-17. The vertical profiles clearly show the intrusive current extending to depths of 500 m for the entire period of observations at station 4 and 6 and for most of the time at stations L and M. In view of the weak stratification measured at depths greater than 500 m, the velocity

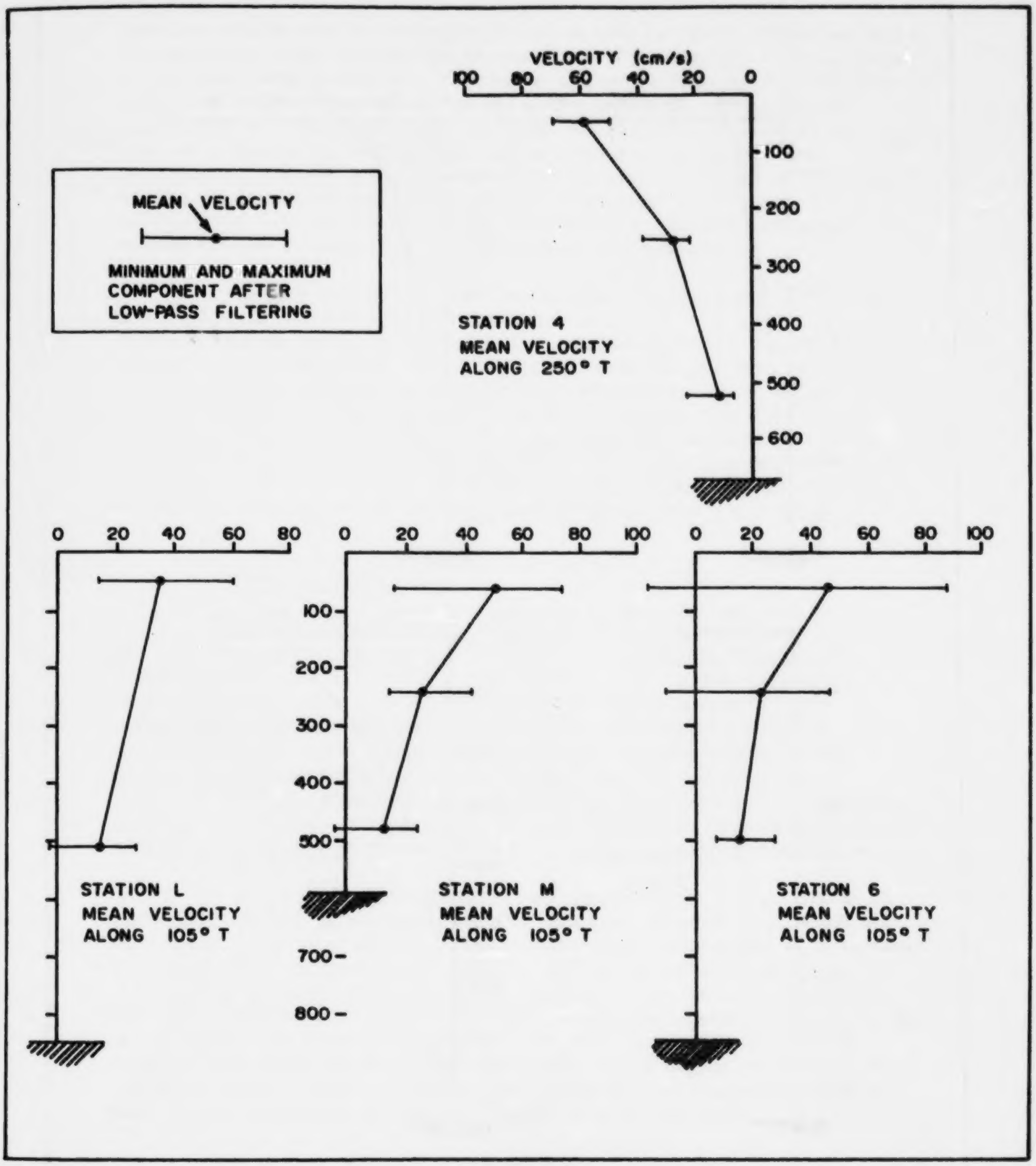


Figure 5.2.3-17: Average vertical profiles of the intrusive currents as measured at mooring stations 4, 6, L and M. The horizontal bars represent the extrema of the currents after a low pass filter has been applied to remove daily and higher frequency variations.

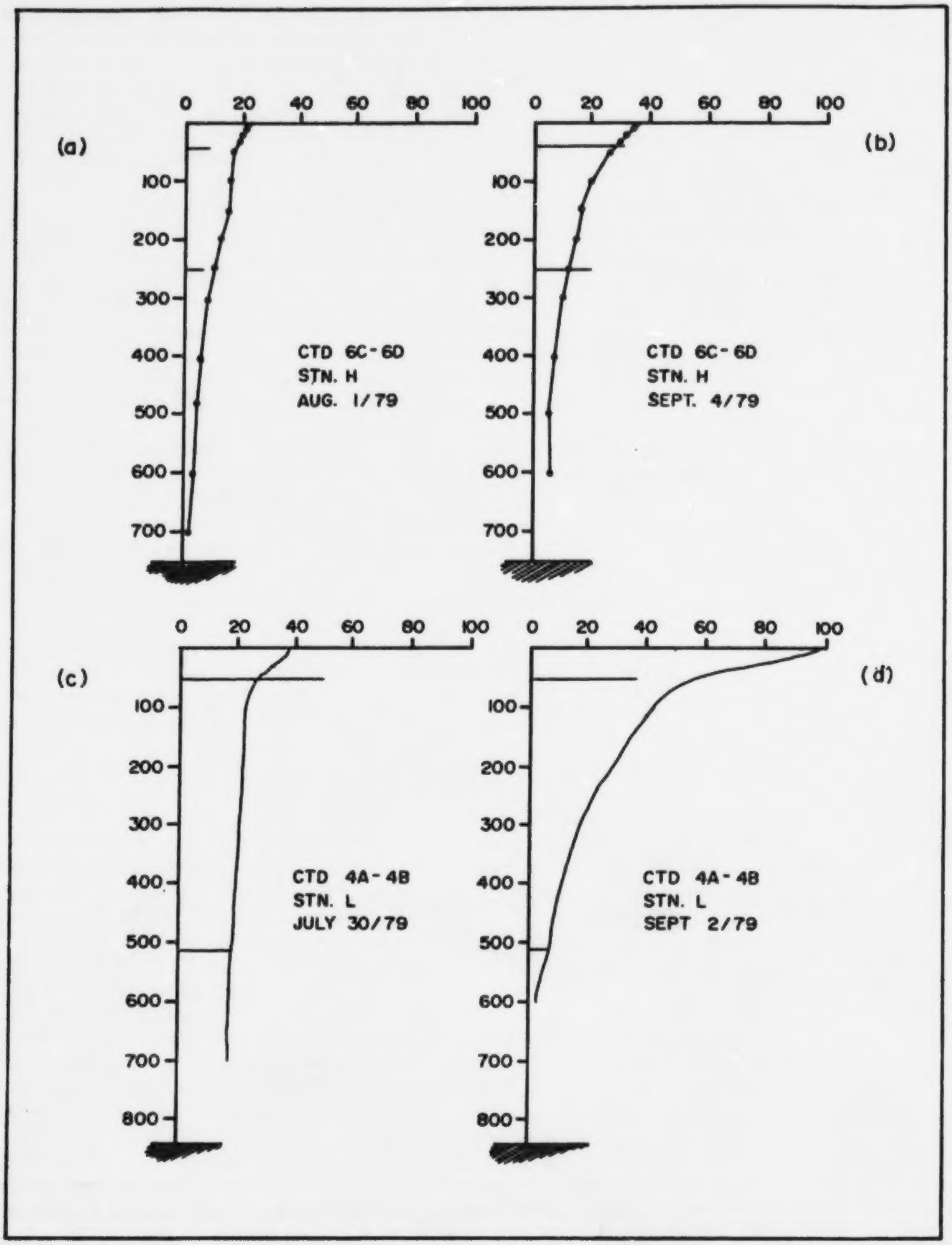


Figure 5.2.3-18: The geostrophic velocity shear computed from CTD normalized to simultaneous direct current meter measurements at 500 m depths.

shear at those depths is expected to be small. This, together with the sizeable mean velocities measured at 500 m depth, ranging from 12-16 cm/s, imply that the intrusive current often extends to the bottom of eastern Lancaster Sound where measured depths do not exceed 800 m. One such case is shown in Figure 5.2.3-18(c) at station L where the current at 500 m measured 18 cm/s. The geostrophic current profiles from CTD casts on July 30 at stations 4A and 4B indicate that the shear is less than 1 cm/s per 100 m over depths from 500 to 700 m. Thus, the current would be expected to extend to the bottom, 700 to 840 m deep in this area.

In the mid-Sound portion of the intrusive current, the mean velocities from the current meter data are not as representative of the mean intrusive current profile due to the wanderings of the flow. However, the intrusive current is clearly evident in the current meter data at nominal depths of 35,250 and 500 m at station H (see Figure 5.2.3-19) both in the strong southerly flows measured at each depth and the vertical correlations of variations in the current. At this site, the intrusive current can extend to the bottom, as shown from the combined geostrophic shear and current meter data of September 4, 1979 (Figure 5.2.3-18(b)).

Frontal Structures

CTD data measured along vertical cross-sections through the intense intrusive current reveals large horizontal density gradients (Figure 5.2.3-20). The upward tilting isopycnals associated with the intrusive current reflect an approximate geostrophic balance between the internal pressure gradient and the Coriolis force. One consequence of these large horizontal gradients, often referred to as fronts, is the reduced local vertical density gradient in comparison to those measured on either side of the front. The reduced stratification of the water column allows for greater vertical movements than in neighboring areas.

Frontal structures have been associated with regions of large biological productivity. For example, maxima of biological variables (Fournier et. al., 1977) have been identified with oceanic fronts on the Scotian Shelf (Horne, 1978); increased vertical transports of nutrients along the fronts are believed responsible for the enhanced biological activity. Similar upward transports may occur along the fronts associated with the intrusive current in eastern Lancaster Sound. This movement would supply nutrients to the biologically active upper zone, possibly contributing to the well known abundance of marine-based life in the area.

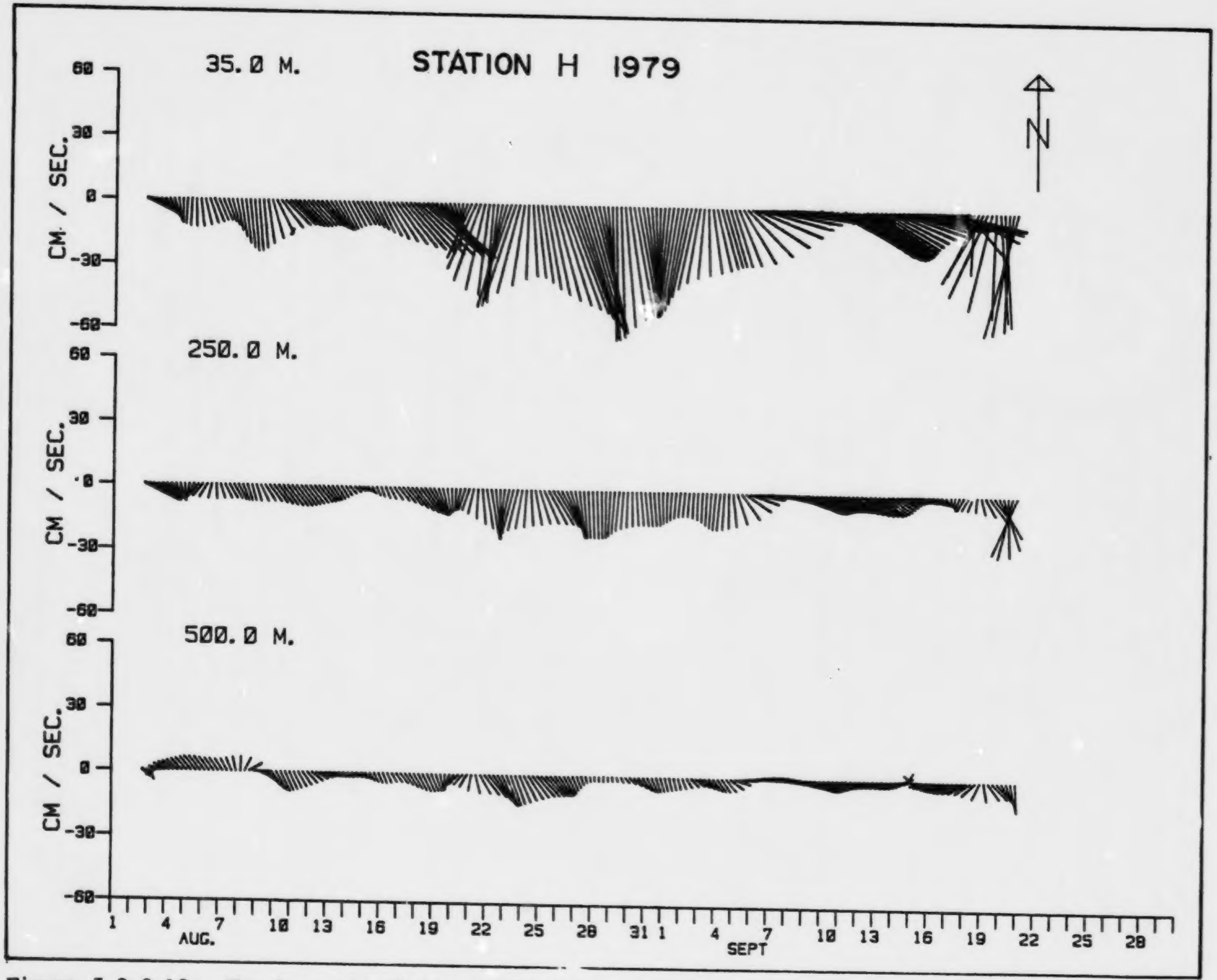


Figure 5.2.3-19: The low pass filtered velocities measured at station H at 35, 250 and 500 m depths.

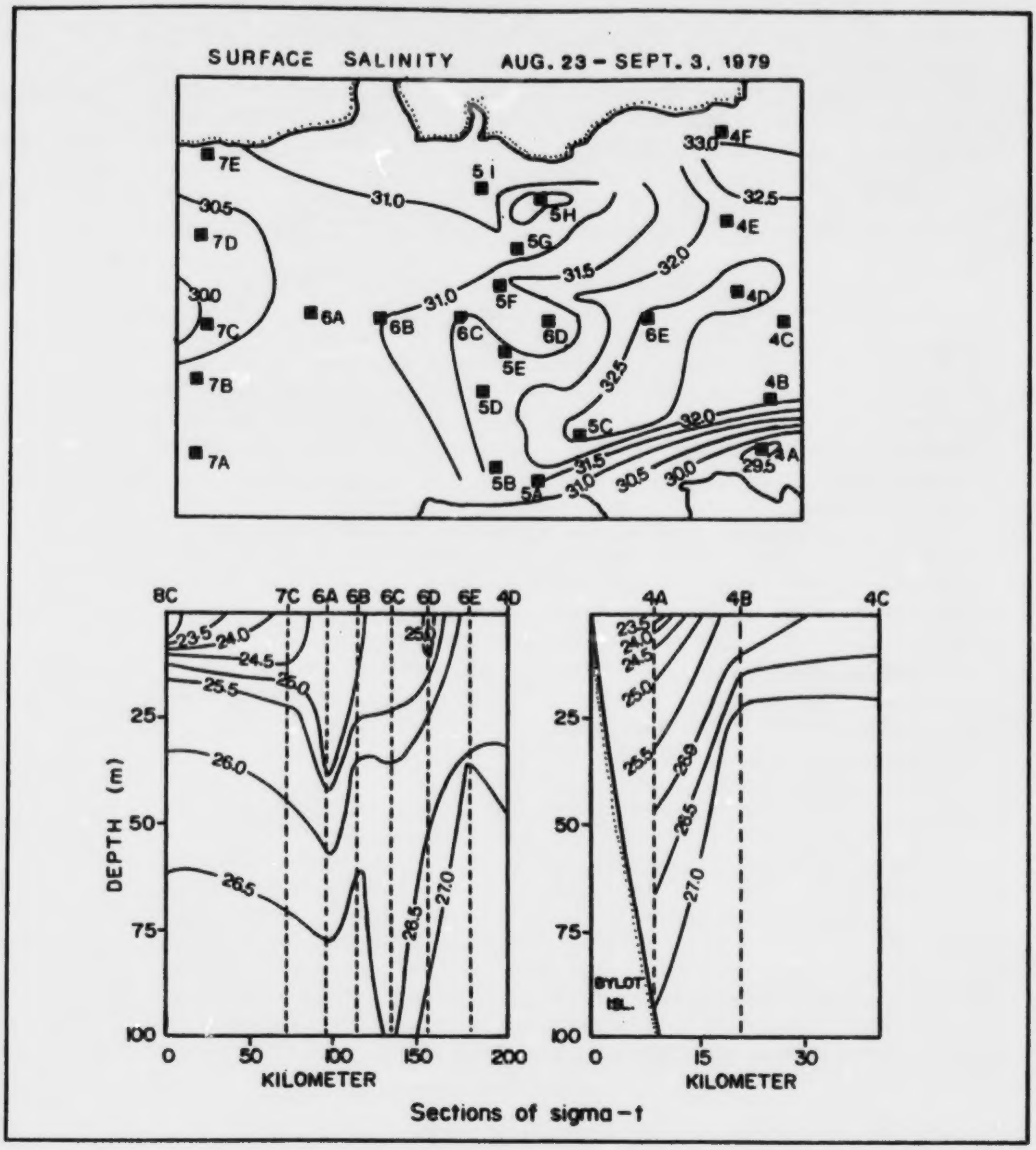


Figure 5.2.3-20: Evidence of frontal structures in the intrusive current from CTD data of August 23 to September 3, 1979.

Summary

The circulation of eastern Lancaster Sound is dominated by a flow of water from east of Devon Island intruding into the Sound on its northern side, crossing southwards through the Sound at distances of 35 to 75 km from the eastern boundary and exiting the Sound along the northwest coast of Bylot Island, with a minor outflow south through Navy Board Inlet. The velocities associated with the intrusive current are generally strong near the surface, decreasing with depth: typical near-surface (4 to 11 m) velocities are 75 cm/s decreasing to 50 cm/s at 40 m depth, 25 cm/s at 250 m depth and 14 cm/s at 500 m depth. Often the current extends to the bottom of eastern Lancaster Sound, which is less than 800 m in depth.

The intrusive current is a permanent feature of the summer circulation of eastern Lancaster Sound: it was present at all times when sufficient measurements were available to resolve it in the 1978 and 1979 data sets collected for the present study. A review of historical oceanographic data of the region shows that its presence was consistent with the derived circulation patterns (Section 5.8) for eight out of nine years in which sufficient data is available.

Important spatial and temporal variations occur in the intrusive current. With the detailed 1979 data set, it was found that the current has two modes of cross-Sound spatial patterns, characterized by either southeastwards movement towards northwest Bylot Island or south to southwestwards flow towards Borden Peninsula. Supporting evidence for this variation was found in the summer data of Fissel and Wilton (1978). The intrusive current alternates between the two modes, typically persisting in either mode for a period of several days.

The flow off Borden Peninsula is characterized by complex circulation features, apparently a result of the intrusive current meeting the outflow of Arctic Water passing through Lancaster Sound from the west. Lacking sufficiently detailed observations in this area, it was not possible to delineate a complete description of the circulation. However, patterns observed included an easterly flow in mid-Sound accompanied by an anti-cyclonic gyre off Borden Peninsula, an easterly flow along the Borden Peninsula coastline, and an anti-cyclonic loop extending from the northwestern tip of the Borden Peninsula into the northern half of Lancaster Sound (Figure 5.2.3-11).

The width of the intrusive current appears to increase in the course of its flow through the Sound. In the northern portion, the instantaneous width may be less than 10 km at times but as it crosses the Sound the upper bound of the current width increases to 15 - 30 km. As the current flows out of the Sound off Bylot Island it can be wider yet, presumably due to the combined influence of the intrusive current and the flow from western Lancaster Sound.

Temporal variations at fixed locations in eastern Lancaster Sound are dominated by the major current patterns. Off southern Devon Island, the currents of the intrusive flow are steady in direction with relatively small variations in speed. In the mid-Sound region, the current variations are dominated by long periods (10 - 30 days) corresponding to the alternating modes of the intrusive current. The temporal variations in the outflow from Lancaster off Bylot Island are relatively large and appear to vary significantly over relatively short spatial scales of 10 km.

Associated with the intrusive currents are oceanic fronts observed in cross-sections of water properties. These fronts, reflecting the large horizontal density gradients which approximately balance the Coriolis force due to the intrusive current, persist throughout the summer just as the intrusive current does. They provide a means for enhanced vertical motions due to reduced stratification. Along the fronts, increased upward movement of nutrients may occur resulting in enhanced biological productivity.

5.2.4 Central Disordered Zone

The central disordered zone occupies the central part of the entrance to Lancaster Sound. The zone is bounded to the north, south, and west by the intrusive current. The eastern bounds are limited by the data coverage of the study; discussion will be limited to the area west of 73° longitude.

Surface Circulation-Summer 1979

The most comprehensive data on the summer surface circulation of this area are the drogued drifter data of 1979. Ten of the drifters released in 1979 spent some time in the central zone. Figure 5.2.4-1 is a plot of the vector average velocities of all drogued drifter trajectories in this zone during summer 1979. The numerical values are the number of velocities which contribute to the average. Box sizes for averaging were 0.167° latitude by 0.5° longitude. Also shown are the current meter mooring locations. Figure 5.2.4-1 shows that in the central disordered zone, to the west of about 77° W, the vector average surface flows are weak (generally less than 5 cm/sec) and variable in direction. East of 76° W, although the data coverage is less thorough, the flow appears to be more organized with speeds of up to 25 cm/sec in an easterly direction. Knowledge of the eastern part of the zone is limited, with data from only two drifters, and little more will be said about this section of the central zone.

Figure 5.2.4-1 suggests little net motion; however, actual drifter speeds in the zone were often on the order of 15 cm/sec. It is the directional variability which produced the low vector average speeds. Figure 5.2.4-2 shows a drifter track (1980) which

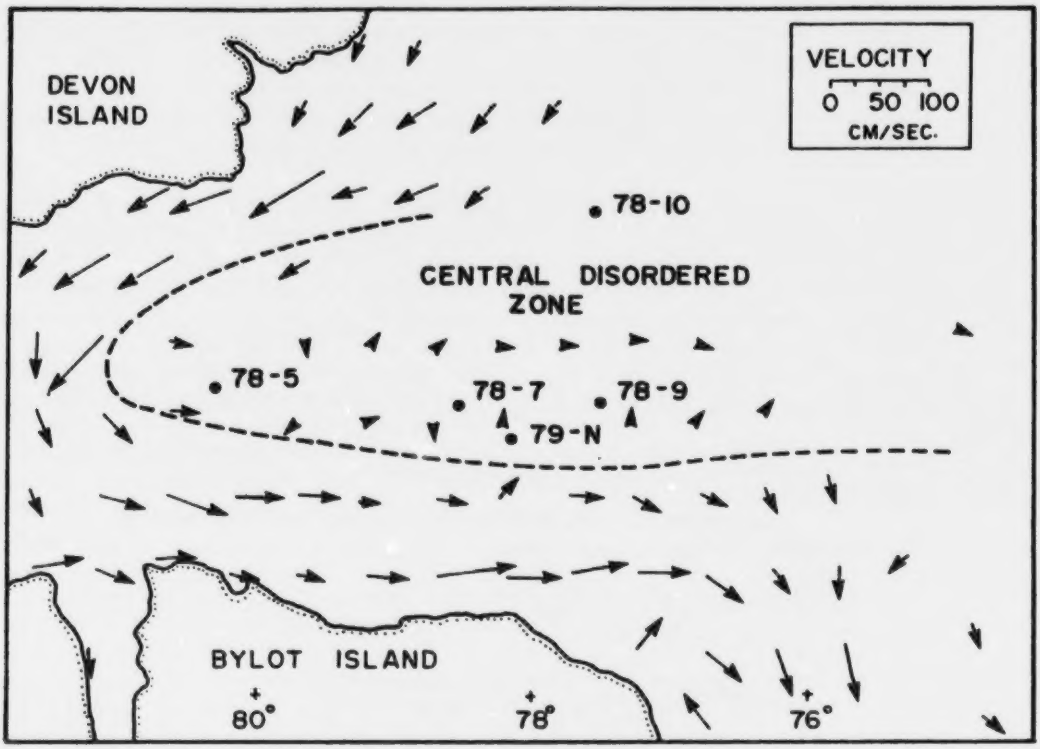

DEVON ISLAND
VELOCITY
0 50 100
CM/SEC.
78-10
CENTRAL DISORDERED ZONE
78-5
78-7
78-9
79-N
BYLOT ISLAND
80°
78°
76°

Figure 5.2.4-1: The vector averaged velocities for grid areas in the Central Disordered Zone from 1979 drifter data.

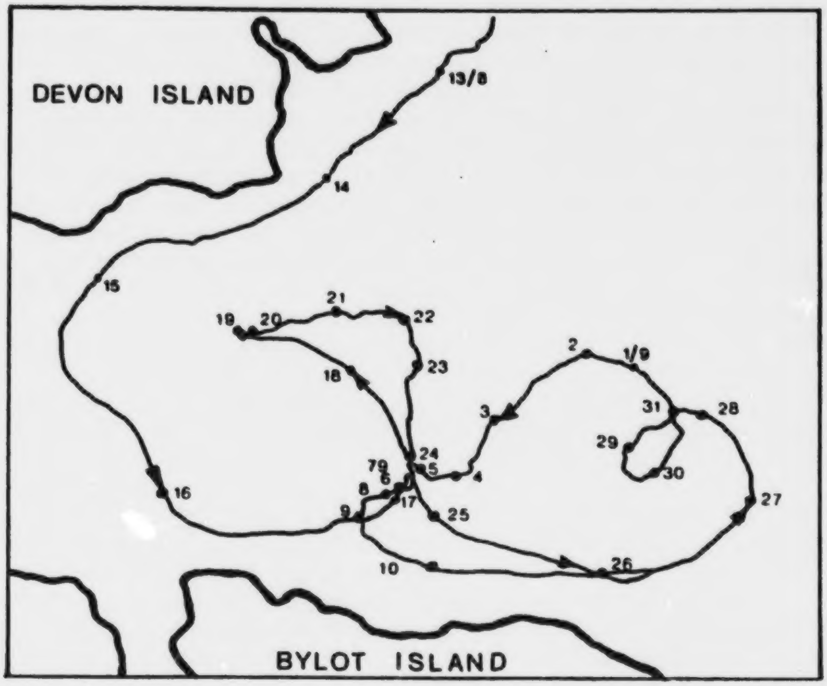

DEVON ISLAND
13/8
14
15
19
20
21
22
23
18
2
1/9
3
31
28
29
30
24
79
5
4
6
8
17
16
9
25
27
10
26
BYLOT ISLAND

Figure 5.2.4-2: The track of drifter 1980 during the summer of 1979.

illustrates the random, though non-zero motion which typifies this central disordered zone. Although surface flow is weak and variable, no drifters exited the zone to the north or west, which indicates a net easterly and/or southerly flow.

Half of the ten drogued drifters which entered the zone were shed from the intrusive current north of Bylot Island (Figure 5.2.4-3). No abnormal wind events were evident at the times of entry which might be expected to produce such spin-offs. In fact winds were generally from the northeast (i.e., onshore). However, if one compares the tracks of two of the drifters, 1982 and 1976, to the dynamic topography (see Figure 5.2.4-4), the drifters were on the offshore edge of what may have been a meander of the strong current north of Cape Liverpool. This may point to the mechanism causing these spin-offs. Of the other five drifters entering the central disordered zone, two were deployed in the zone (1977 and 1979), one spun-off from the edge of the intrusive current as it crossed Lancaster Sound (1969), and two moved north into the region just off Cape Hay (1961 and 1964). The latter two moved north across the usual location of the strong Lancaster Sound outflow. These may have indicated a meander in the flow further to the west, near Cape Hay.

Four of the drifters left the central zone and rejoined the outflow north of Cape Liverpool (Figure 5.2.4-5). The rejoining of the drifters with the main flow occurred along the back side of the meander as indicated by the dynamic heights. This adds further evidence to a possible relationship between the meanders in the Lancaster Sound outflow and the occurrences of entries and exits from the Central Disordered Zone.

Wind forcing does not appear to be a major factor in the near-surface motions in this zone. In fact, the storm event of August 19 in which northerly winds of up to 18 m/sec persisted for two days produced relatively little net motion in the drifter tracks (see Figure 5.2.4-6). Within a day of the beginning of the wind event inertial oscillations were evident in two of the tracks (1975 and 1979) as discussed in section 5.5. By August 22, easterly to southeasterly motions of 10 to 20 cm/sec were measured with the drifters. However, it is not clear that this was a direct response to the strong northwesterly winds which had subsided two days earlier. Another example of the lack of response to wind forcing is provided by the track of drifter 1980 (Figure 5.2.4-2); it left the zone on August 25 and re-entered by spinning off the main flow on August 26, during a period of northeasterly winds. On this evidence, near-surface movements into and out of the Central Disordered Zone do not appear directly related to wind forcing.

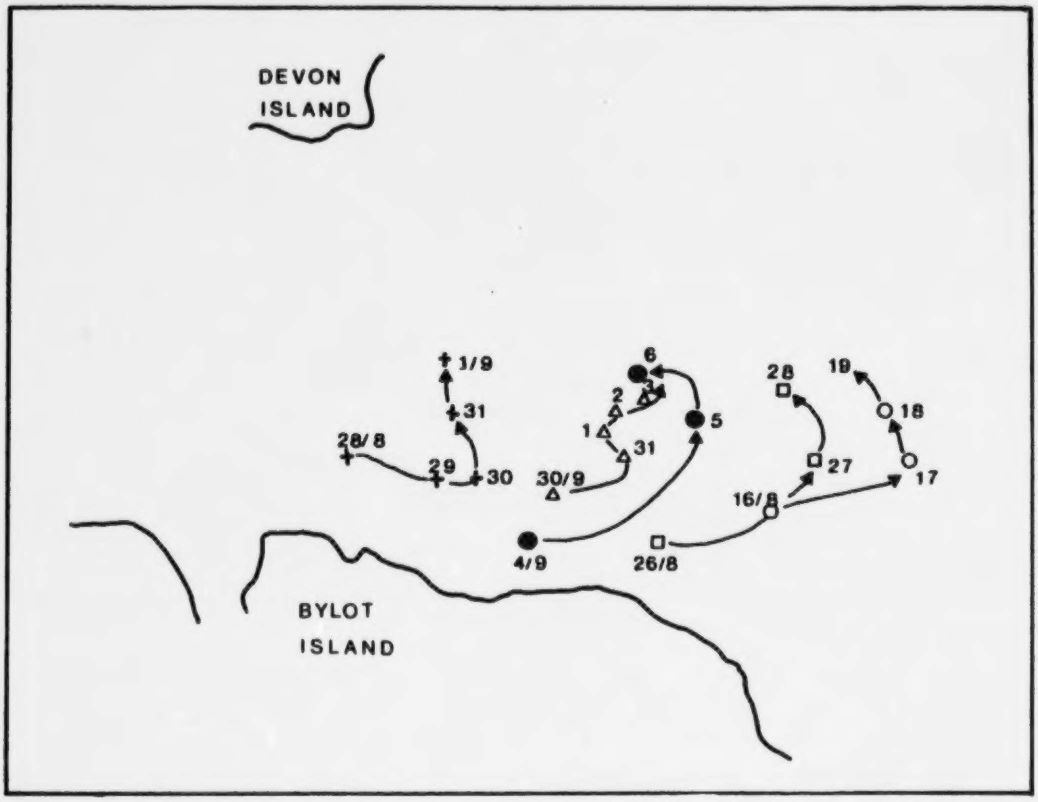

DEVON
ISLAND
1/9
31
28/8
29
30
6
2
3
1
31
5
30/9
4/9
28
19
18
27
17
16/8
26/8
BYLOT
ISLAND

Figure 5.2.4-3: Drifter tracks from 1979 illustrating entry into Central Disordered Zone from Lancaster Sound outflow.

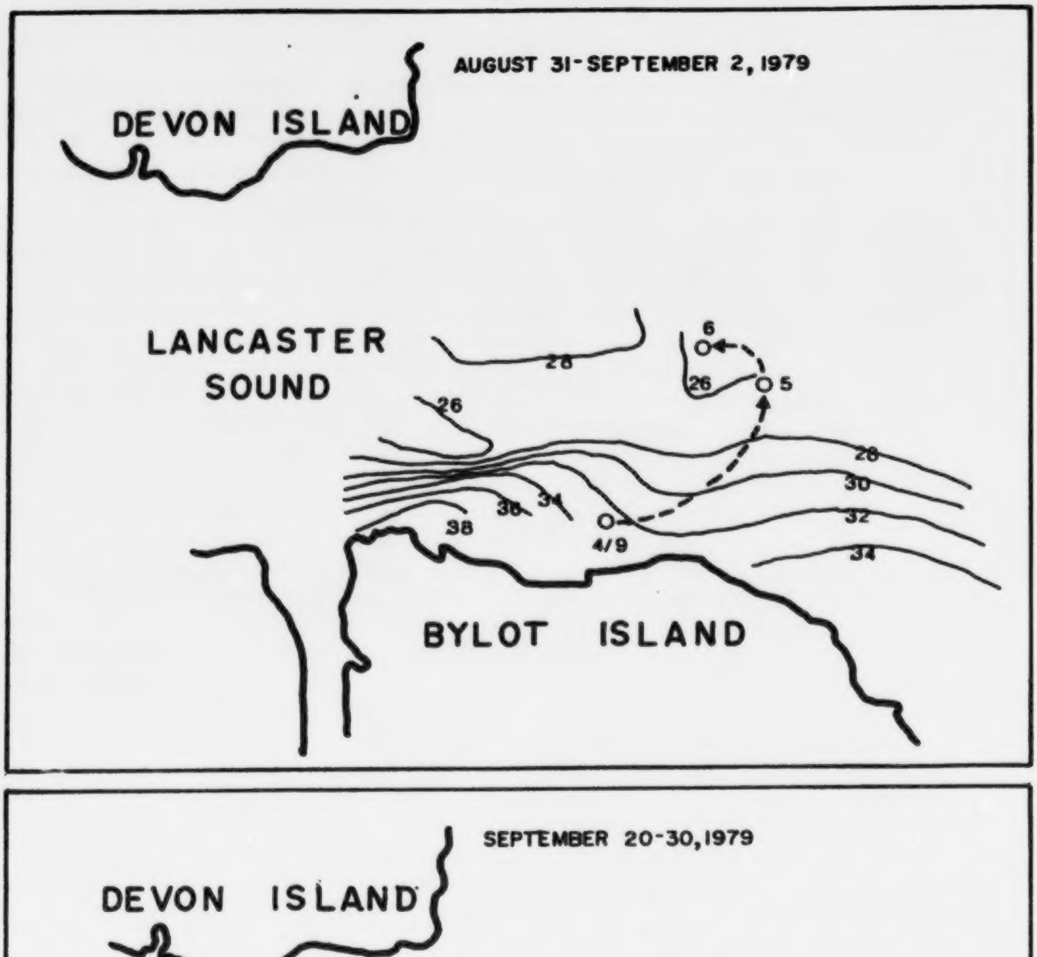

AUGUST 31-SEPTEMBER 2, 1979
DEVON ISLAND
LANCASTER SOUND
28
6
26
5
26
28
30
32
34
38
36
34
4/9
BYLOT ISLAND
SEPTEMBER 20-30,1979
DEVON ISLAND
LANCASTER SOUND
26
28
3
2
1
30
31
32
34
36
38
40
42
30/8
BYLOT ISLAND

Figure 5.2.4-4: Dynamic height anomalies (in dynamic cm) relative to 300 dbar for (a) August 31-September 2, 1979 (along with track of drifter 1976, and (b) September 20-30, 1979 (along with track of drifter 1982).

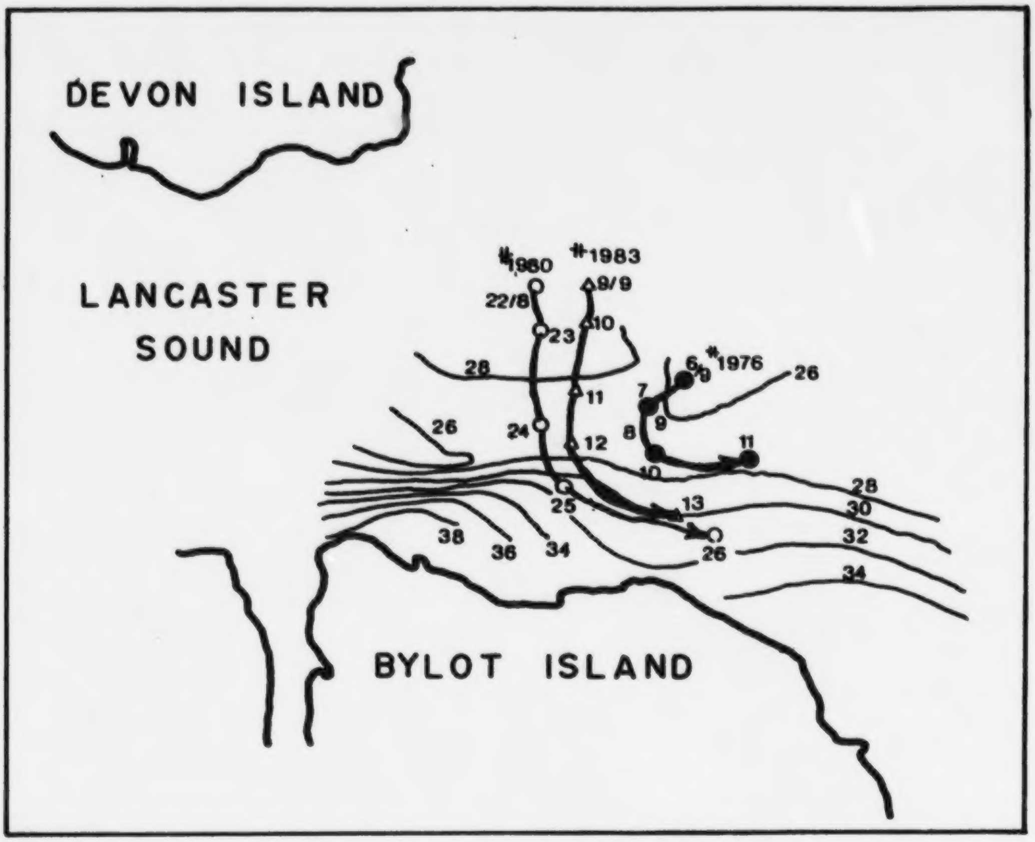

DEVON ISLAND
LANCASTER SOUND
BYLOT ISLAND
#1980
#1983
#1976
22/8
9/9
23
10
28
11
6
9
26
7
26
24
12
8
9
11
10
28
13
30
25
38
36
34
26
32
34

Figure 5.2.4-5: Drifter tracks of 1976, 1980 and 1983 leaving the Central Disordered Zone superimposed on the dynamic heights anomaly of September 3-4, 1979.

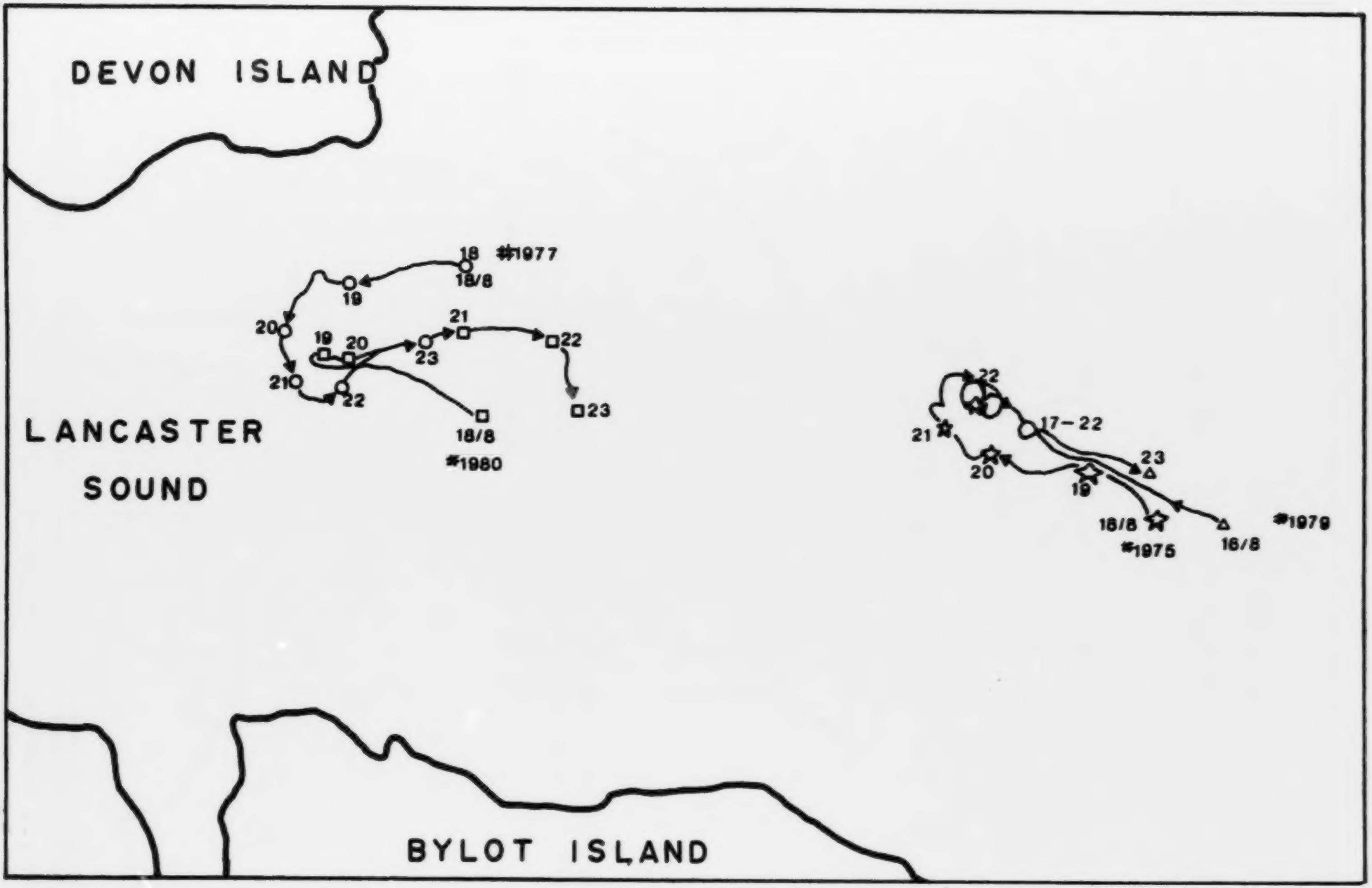

DEVON ISLAND
LANCASTER SOUND
BYLOT ISLAND
#1977
18
18/8
19
20
21
22
23
#1980
18/8
19
20
21
22
23
#1979
16/8
23
#1975
18/8
19
20
21
22
17-22

Figure 5.2.4-6: The movements of drifters 1975, 1977, 1979 and 1980 from August 18-23, 1979 during and after the passage of an intense storm.

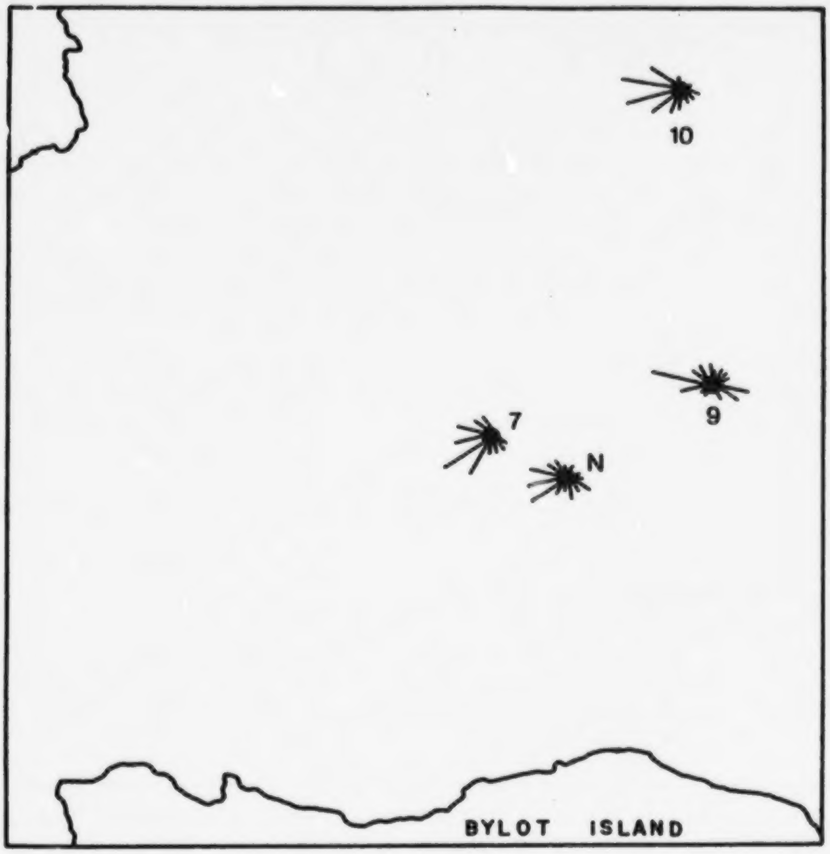

10
7
N
9
BYLOT ISLAND

Figure 5.2.4-7: Directional distribution of currents from 35 m current meters at mooring stations 7, 9, 10 and N.

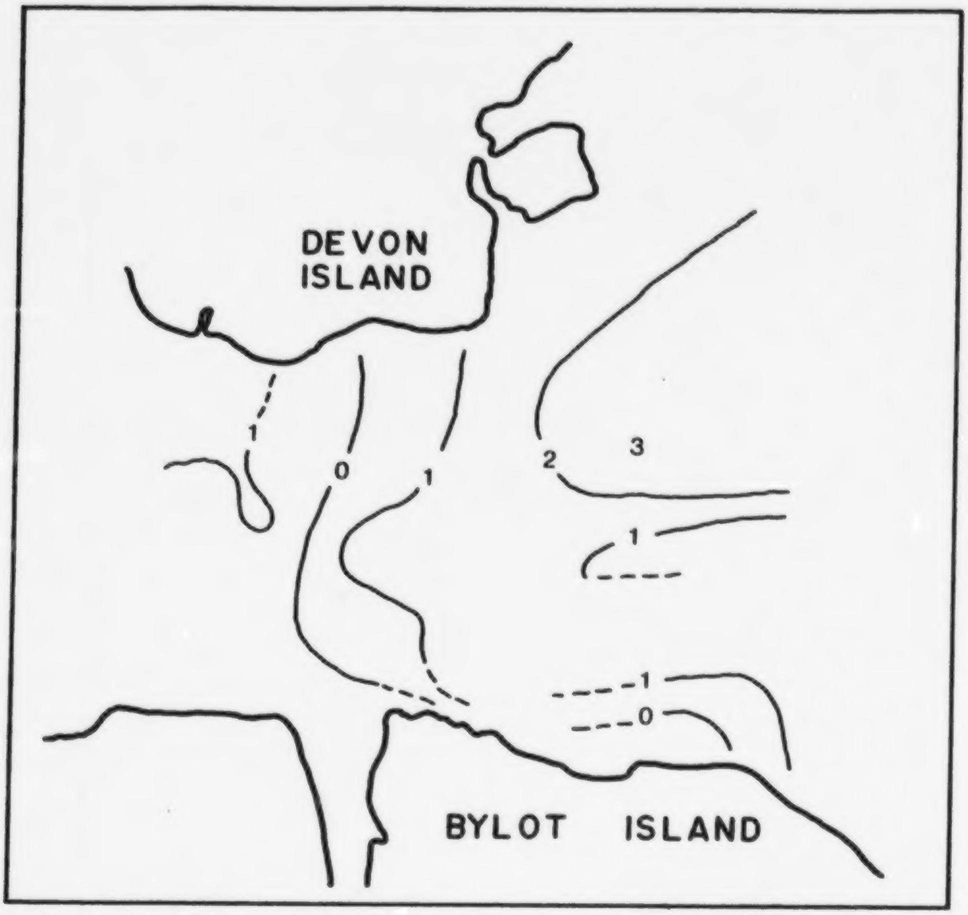

DEVON ISLAND
BYLOT ISLAND
1
0
1
2
3
1
1
0

Figure 5.2.4-8: Surface Temperature (°C at 5 m), period of July 29 to August 4, 1979.

Subsurface Currents-Summer 1979 and 1978

Figure 5.2.4-1 shows the 1978 and 1979 mooring locations. Moorings 7, 9 and N were in the area of the eddy like features indicated by the 1979 drifter data. The upper current meters located at 35 m depth measured average speeds of about 13 cm/sec, with considerable variability in direction (Figure 5.2.4-7). The current meters at 250, 500, and 750 m depth recorded mean speeds of about 7 cm/sec with currents generally westerly and with less directional variability than at the upper meters.

CTD Data

Dynamic height anomalies computed from the 1979 CTD data sets (Figures 5.2.5-2 and 5.2.5-3) support the description above, based on drifter and current meter data. The Central Disordered Zone is characterized by minimum dynamic height anomaly differences as compared to surrounding zones. The resulting weak gradients are a measure of weak geostrophic surface currents, typically with magnitudes of less than 15 cm/s.

During summer the waters of the upper 50 meters of the water column are generally warmed by solar heating. The surface temperature distribution for July 29 - August 4, 1979 (Figure 5.2.4-8) shows that the 1° C isotherm roughly delineates the bounds of the central disordered zone. To the north, south, and west temperatures decrease due to the presence of Arctic outflow water.

Summary

The surface circulation of the central disordered zone is typified by variable flows with speeds on the order of 10-20 cm/sec. Because the flow is extremely irregular, the net movement of the surface waters is small and appears to be directed to the south and east, as indicated by all drifters exiting in these directions. Typical flow speeds are generally reduced to about 8 cm/sec between 250 and 750 m depth, and the direction is steadier and tends to net westerly movements.

5.2.5 Eddy Zone East of Bylot Island

Introduction

The Baffin Current leaves Lancaster Sound along the north coast of Bylot Island. Between Cape Liverpool and the mouth of Pond Inlet, it frequently loses its character as a strong coastal flow and detaches itself from the northeast corner of the island with eddies and countercurrents being observed along the east coast of Bylot Island, from time to time. The circulation of the region east of Bylot Island differs considerably from the rest of the Baffin Current, and therefore will be treated separately in this section.

Eddies and disorders in the flow in this region have been observed before. Large-scale eddies were observed off the east coast of Bylot Island in 1960 and 1966 (Muench 1971). The station spacings in those years were not close enough to define eddies whose scales were less than 50 km.

The description of the circulation in this region will be drawn from the data provided by drogued drifters released in 1978 and 1979, and the CTD data collected in those same years. No current meters were moored in this area in either year. One drifter released in 1977 (Fissel and Marko, 1978) went past the east coast of Bylot Island and will be considered in the description of the circulation.

General Circulation Pattern

The Baffin Current flows southeast, along the coast of Bylot Island, but is frequently distorted by both large and small scale perturbations. Figure 5.2.3-5 shows the dynamic topography of the surface relative to a 300 dbar reference level for three different periods during the summer of 1978. The general southeastward trend of the flow is evident, but a large-scale meander is present east of the southern tip of Bylot Island. This meander may be partly caused by the presence of a seamount 46 kilometers east of the island (see Figure 5.2.5-1). A shallow (150 meters) shelf is present along the coast, broadening from less than 1 km in width at the northern end to 24 km width at the southern tip of the island. It is possible that the presence of the shelf may be responsible for the tendency of the current to stay away from the coast itself. Figures 5.2.5-2 and -3 show the dynamic topography of the surface relative to 300 dbars for 4 periods during the summer of 1979. Again, meanders and eddies are visible, often located near the seamount off the southern tip of the island. In all cases, the flow tends further offshore as it moves along the coast of the island. In the examples in Figures 5.2.5-3 and 5.2.5-2(b) (and suggested in 5.2.5-2(a)), it moves much further offshore than the edge of the shelf.

Since 1979 has the most detailed data set, the pattern of circulation in that year will be considered first. Figures 5.2.5-4(a) -5(a) and -6(a) show the average velocities for all drifters which passed through squares 0.50° in longitude by 0.167° in latitude during the period covered by each chart. Consider the period August 12 to 30 (Figure 5.2.5-4(a)), which overlaps the period covered by the dynamic topography shown in Figure 5.2.5-3(c). The average velocities show the surface current to be moving at about 50 cm/sec along the north coast of Bylot Island to Cape Liverpool, where it continues east, moving away from the shoreline. This movement away from the coast may be seen in Figure 5.2.5-3(c) as well, although the velocities (relative to 300 dbar) are lower, 20 to 26 cm/sec. Off the east coast of the island itself, the drifters indicated flow along the coast, at approximately 35 cm/sec. The flow moves slightly offshore to the south, from 10 km off Cape Fanshawe to about 20 km off Cape Burney. There were only two drifter tracks in this zone at that time, however, which may be too small a sample. The dynamic topography in Figure 5.2.5-3(c) shows the flow 55 km offshore at Cape Burney, at approximately 35 cm/sec and 25 km in width. It is offshore of the seamount in Figure 5.2.5-1 (shown also by the X in Figure 5.2.5-3(c). The seamount is located near the centre of the large anti-cyclonic eddy which brings the flow back in toward the mouth of Pond Inlet. The drifter tracks in Figure 5.2.5-4(b) do not extend far enough south to confirm that feature due to the failure of both drifters in this zone.

Figure 5.2.5-5(a) shows the average velocities derived from the set of tracks shown in Figure 5.2.5-5(b), which cover the period from August 31 to September 12, 1979. Three drifters travelled east past Cape Liverpool at speeds up to 75 cm/sec. Two of them then turned south from a point 50 km east of Cape Fanshawe and moved back inshore to Cape Graham Moore. The period covered by Figures 5.2.5-5(a&b) falls between those covered by the dynamic topographies in Figures 5.2.5-3 (c) and (d). In these figures the flow is shown as having moved closer to the Bylot Island coast at the end of September, and the drifter paths in Figure 5.2.5-5 (a) and (b) may represent a transitional stage.

The majority of the drifters released in 1979 went past the Bylot Island coast between September 13 and October 29. The average velocities and drifter paths for this period are shown in Figures 5.2.5-6 (a) and (b), respectively. Figure 5.2.5-3(d) shows the dynamic topography off the east coast of Bylot Island for the period September 26 to 30. A strong (48 cm/sec, relative to 300 dbar) alongshore flow is shown within 20 km of the coast, with a weaker (11 cm/sec, relative to 300 dbar) flow outside of that, which moves out to 100 km offshore at the southern tip of the island. The strong flow near the coast turns into the mouth of Pond Inlet at the end of the Bylot Island shelf. The average drifter velocities in Figure 5.2.5-6(a) show a somewhat more complex situation. A band of southeastward flow of about 45 cm/sec exists, centred at 35 km offshore. Between this band and the coastline, no organized flow is apparent. Reference to Figure 5.2.5-6(b) reveals a set of eddies off both Cape Fanshawe and Cape Burney, which occupy the zone inshore of the southeastward flow. East of the above mentioned southeastward flow, a band of northerly motion (centred about 65 km offshore) with speeds of 15-30 cm/sec is apparent. As may be seen from Figure 5.2.5-6(b), this was described by four drifters, all of which passed through it in early October. Drifters 1977 and 1983 moved north through this zone between October 3 and October 10, then turned east and moved southeastward, 140 km offshore at speeds up to

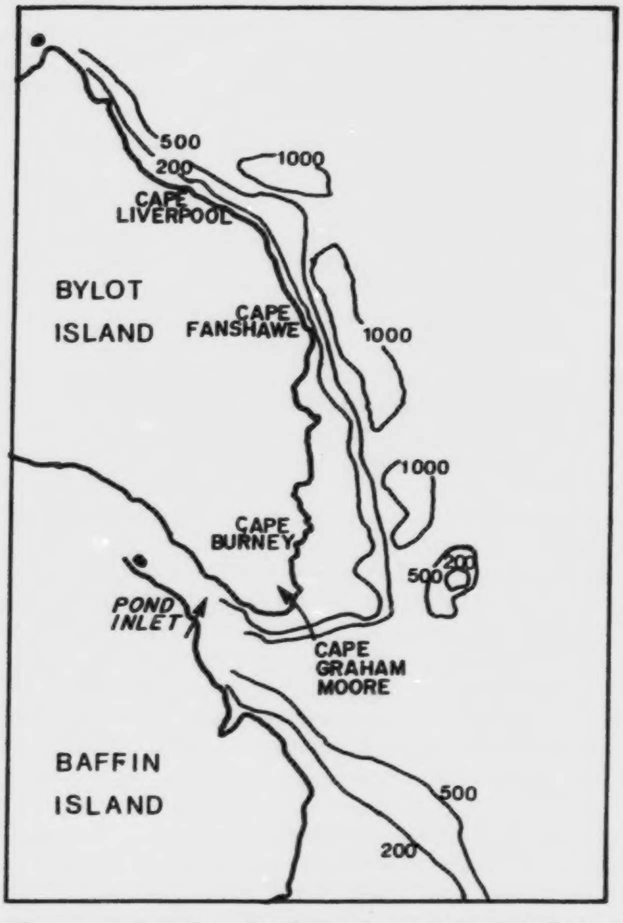

500
200
1000
CAPE LIVERPOOL
BYLOT ISLAND
CAPE FANSHAWE
1000
1000
CAPE BURNEY
500
200
POND INLET
CAPE GRAHAM MOORE
BAFFIN ISLAND
500
200

Figure 5.2.5-1: Bathymetry east of Bylot Island (1:2,000,000 scale) Depths are in meters.

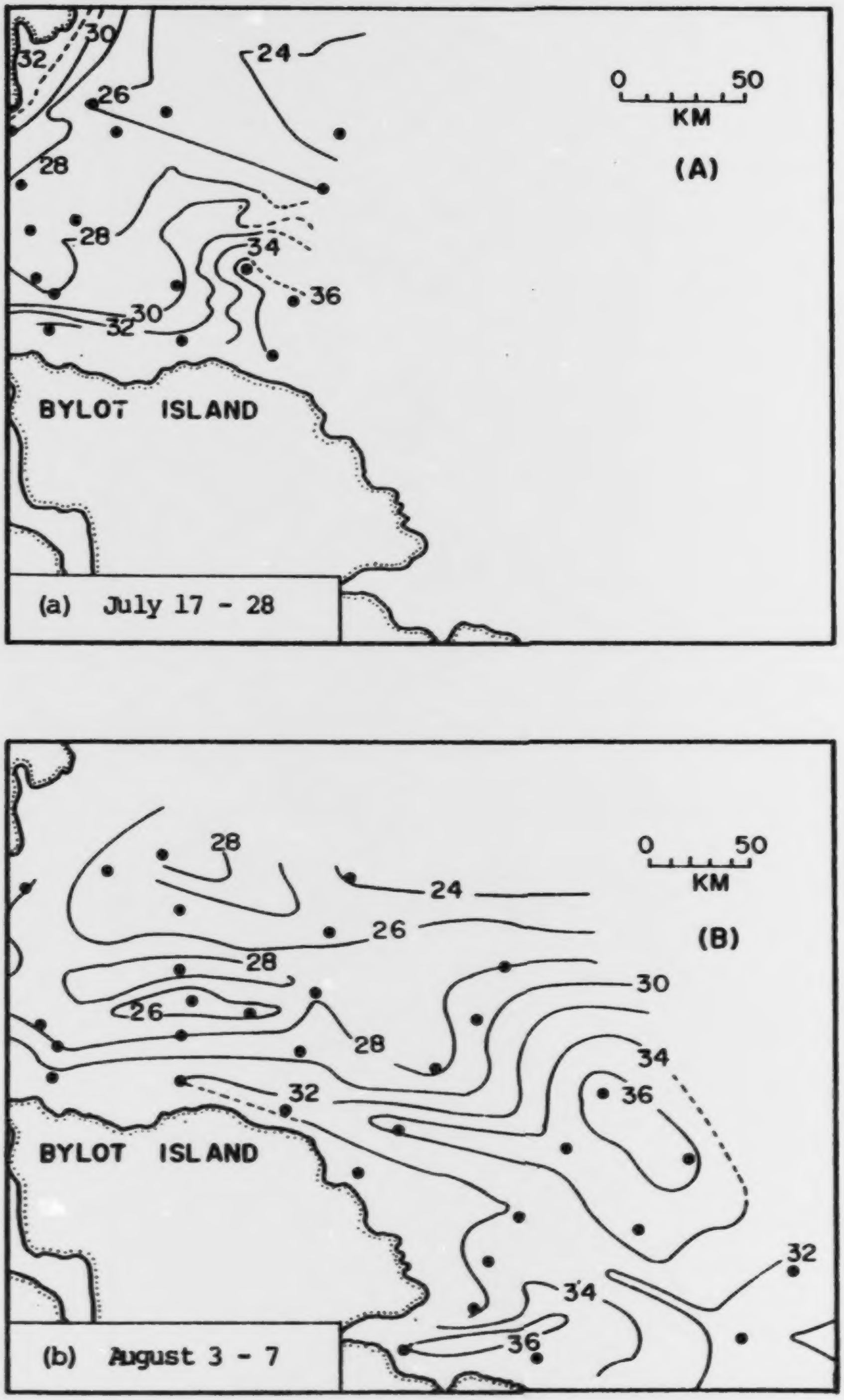

32
30
24
26
28
28
34
36
30
32
0 50
KM
(A)
BYLOT ISLAND
(a) July 17 - 28
28
24
26
28
26
28
30
34
36
32
32
34
36
0 50
KM
(B)
BYLOT ISLAND
(b) August 3 - 7

Figure 5.2.5-2: Dynamic topography of the surface relative to 300 dbar, 1979.

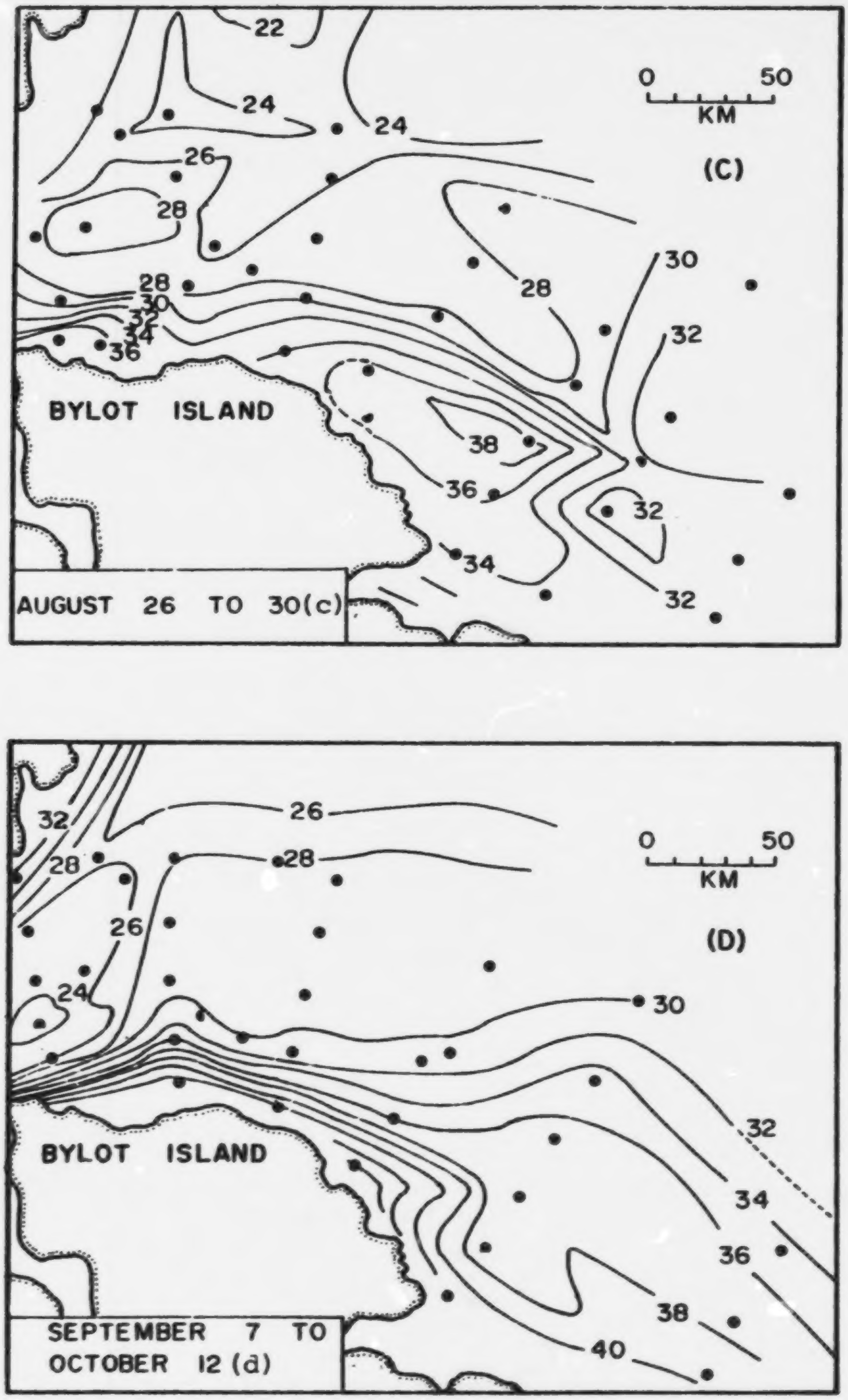
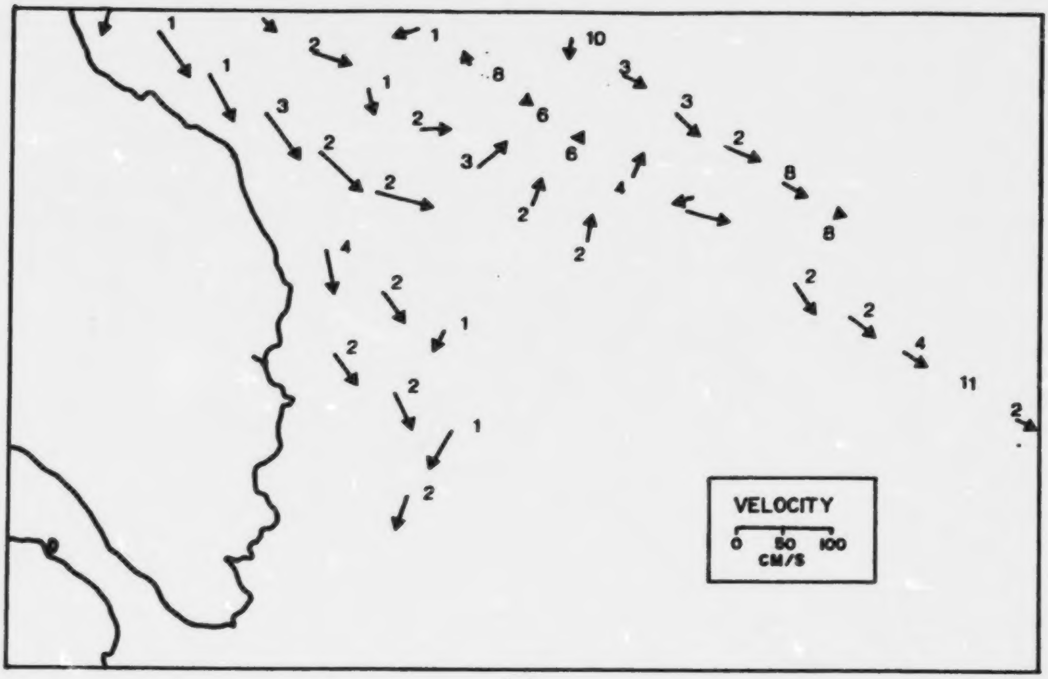
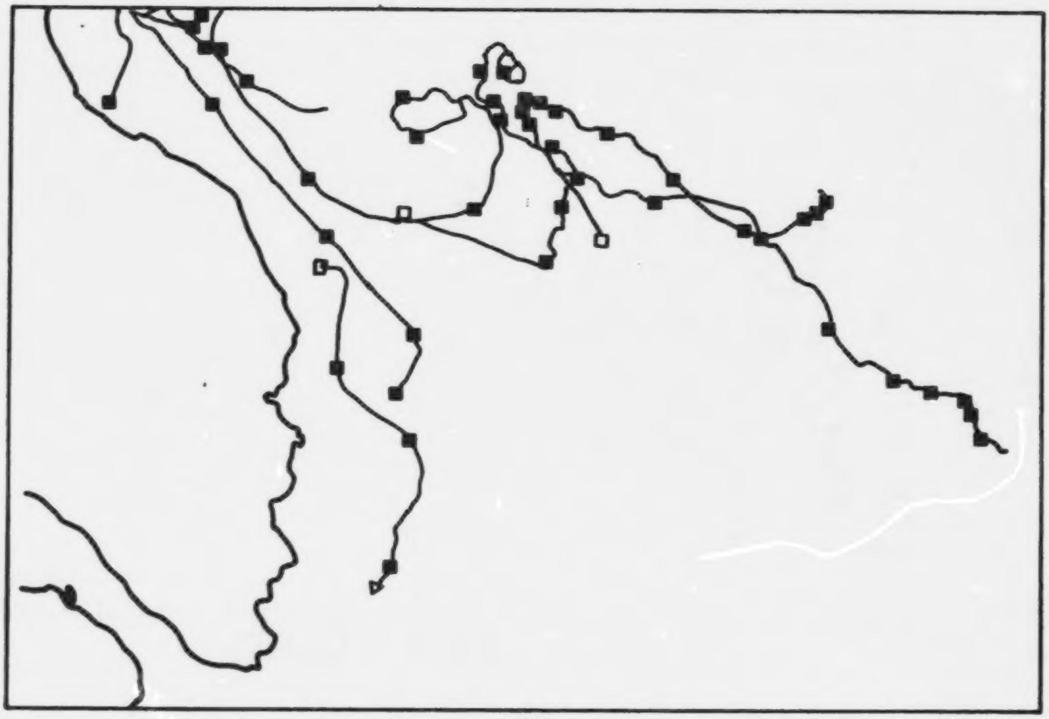

22
24
24
26
28
0 50
KM
(C)
30
28
28
30
32
34
36
32
BYLOT ISLAND
38
36
32
34
32
AUGUST 26 TO 30(c)
32
26
28
28
0 50
KM
26
(D)
24
30
BYLOT ISLAND
32
34
36
38
40
SEPTEMBER 7 TO
OCTOBER 12 (d)

Figure 5.2.5-3: Dynamic topography of the surface relative to 300 dbar in 1979.


1
1
2
1
10
8
3
1
3
6
2
2
3
6
2
2
4
2
3
2
8
8
4
2
2
2
1
2
2
4
2
11
2
1
2
VELOCITY
0
50
100
CM/S

(a)



(b)

Figure 5.2.5-4: Composite of drifter tracks and averaged velocities, August 12-30, 1979.

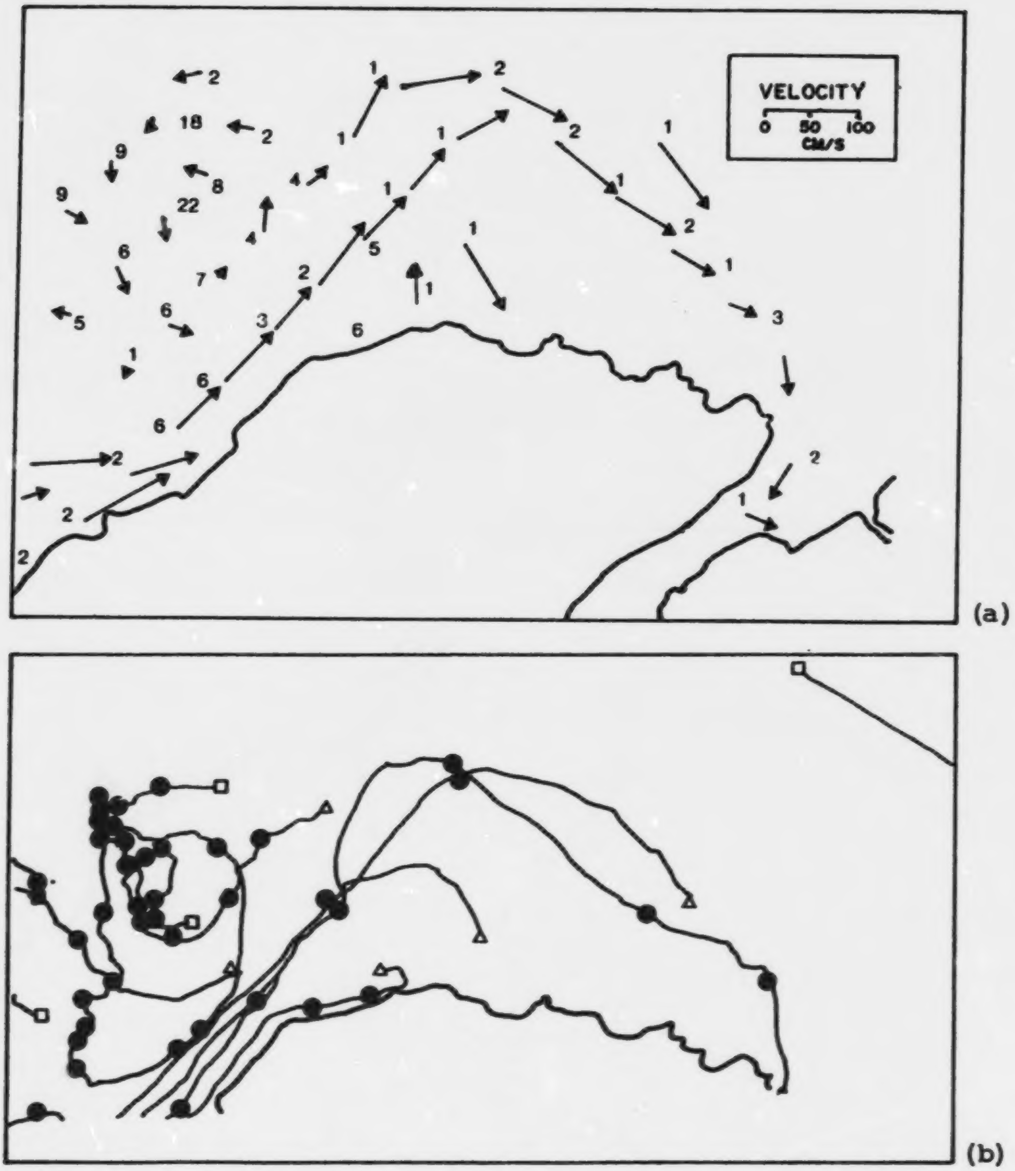

VELOCITY
0 50 100
CM/S
2
18
2
9
8
9
22
6
7
5
6
1
6
6
2
2
2
1
1
2
4
4
1
2
1
3
5
1
1
6
2
1
1
2
1
3
2
1
(a)
(b)

Figure 5.2.5-5: Composite of drifter tracks and averaged velocities, August 31 - September 12, 1979.

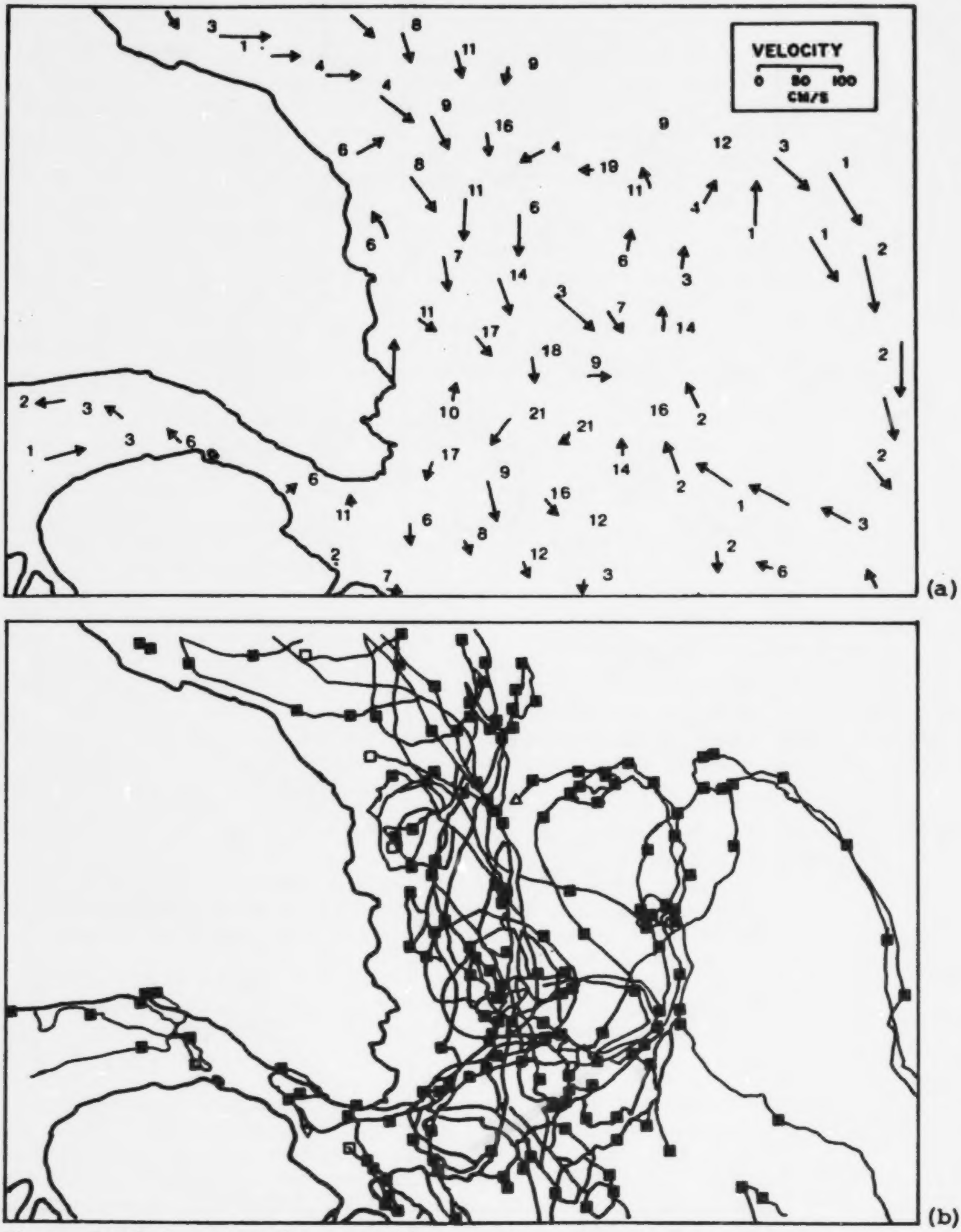
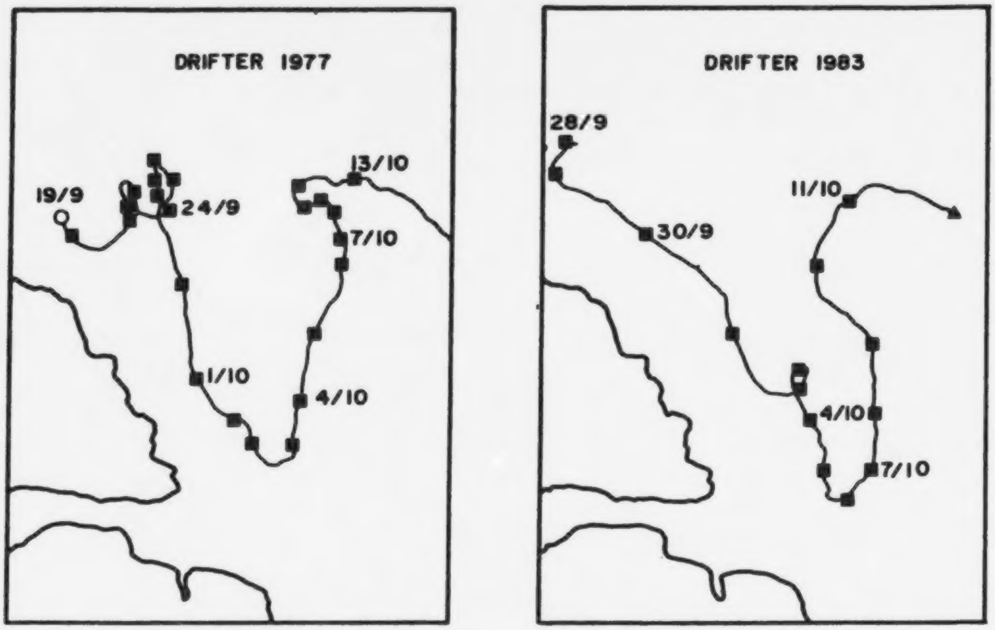
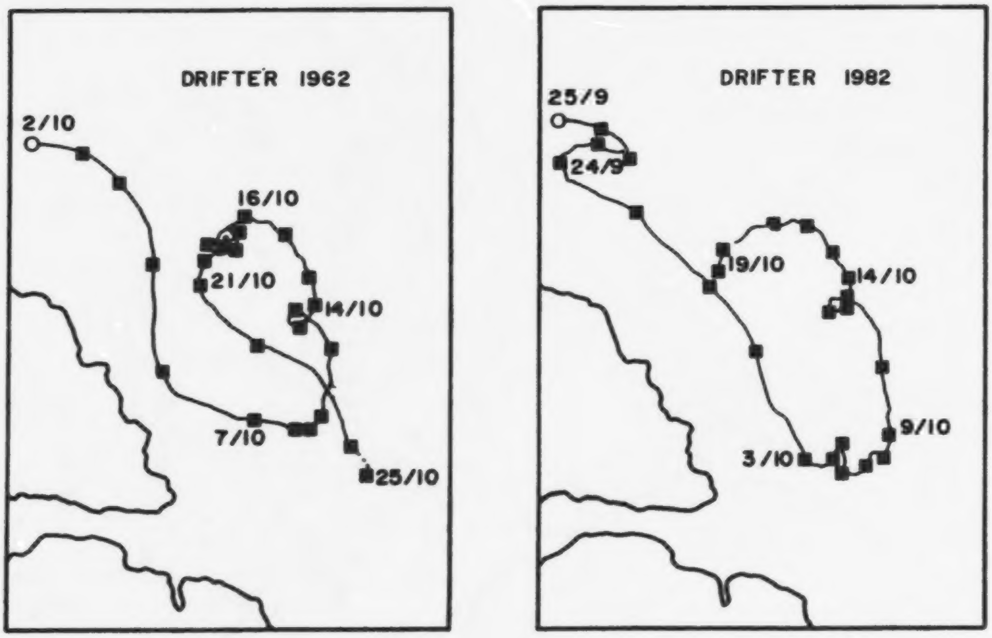

VELOCITY
0
50
100
CM/S
3
1
8
11
9
4
4
9
16
9
12
3
1
6
8
4
19
11
4
11
6
1
6
1
2
7
6
14
3
3
11
7
14
17
18
9
2
2
3
10
21
16
2
21
1
3
6
17
14
2
2
6
9
16
1
11
12
3
6
8
12
2
2
6
7
3
(a)
(b)

Figure 5.2.5-6: Composite of drifter tracks and averaged velocities, September 13 - October 29, 1979.


DRIFTER 1977
19/9
24/9
13/10
7/10
1/10
4/10
DRIFTER 1983
28/9
30/9
11/10
4/10
7/10

(a) (b)

Figure 5.2.5-7(a)&(b): Tracks of drifters 1977 and 1983 showing offshore northward counterflow.


DRIFTER 1962
2/10
16/10
21/10
14/10
7/10
25/10
DRIFTER 1982
25/9
24/9
19/10
14/10
9/10
3/10

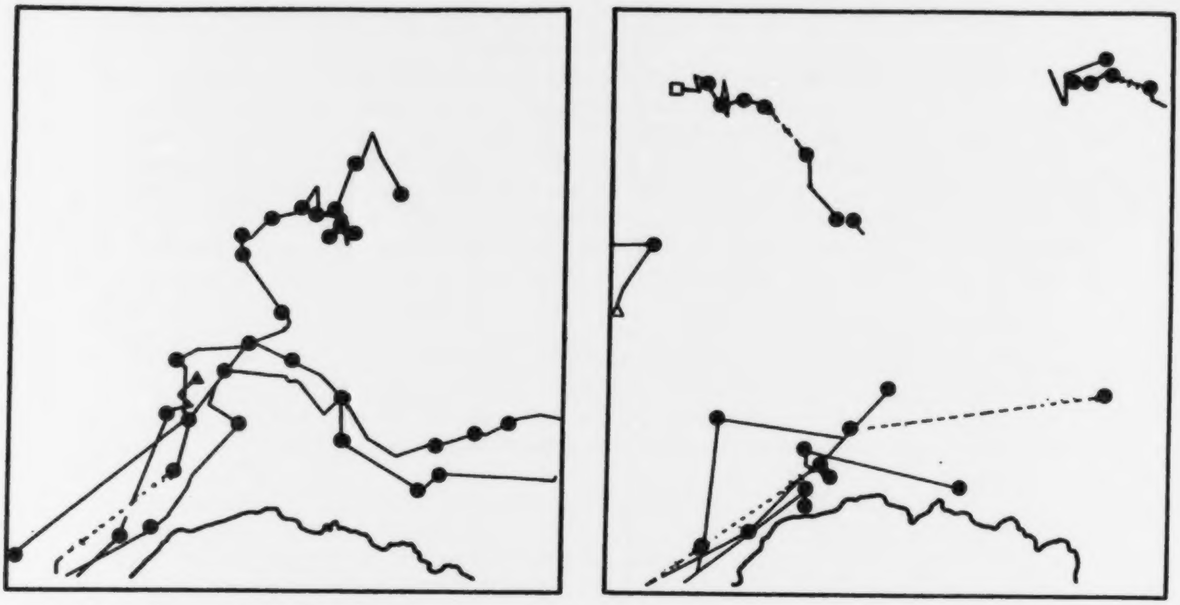
(a) (b)

Figure 5.2.5-8(a)&(b): Tracks of drifters 1962 and 1982 showing offshore northward counterflow.

60 cm/sec. They appear to have been describing an anticyclonic gyre, about 65 km in diameter, centred 100 km east of Cape Burney. Drifters 1962 and 1982 moved north in the same zone (65 km offshore) about 6 days later (October 9 to October 16), but then turned west toward shore before proceeding southeastward again. The individual tracks of these 4 drifters may be seen in Figures 5.2.5-7(a) and (b) and 5.2.5-8(a) and (b). A similar large anticyclonic gyre may be seen in the dynamic topography of Figure 5.2.5-3(b), which covers the period August 3 to August 7, 1979. No drifters were in the area at this time, but the gyre shown agrees in location, scale and sense with that described by drifters 1977 and 1983 in the first half of October. Such a gyre is not visible in the dynamic topography of Figure 5.2.5-3(d) (September 26 to 30), which suggests that the lifetime of such features must be approximately two weeks or less.

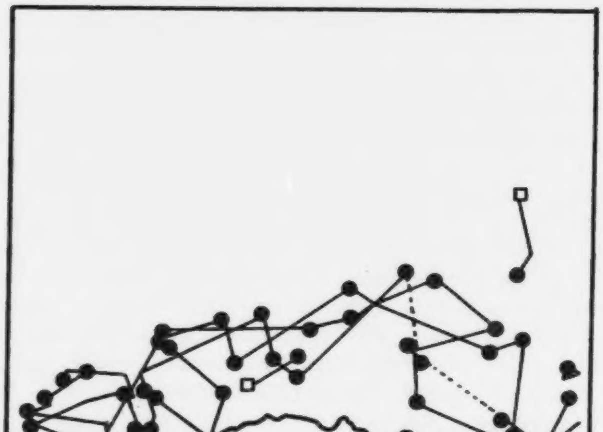
The 1978 drifter data, the tracks from which are shown in Figures 5.2.5-9(a), (b) and (c), does not contain detail equal to that in the 1979 tracks because of the inferior performance of the Nimbus-6 satellite in 1978 (Fissel, 1980). There are large gaps in some of the tracks, and the smaller scale motions are not resolved. Some of the larger features are discernible, however. Figure 5.2.5-9(a) shows three drifters moving east past Cape Liverpool, to a point 70 km offshore of Cape Fanshawe. Their average speed upon leaving Cape Liverpool was 65 cm/sec. They then turned southeast to drift about 30 km offshore at speeds of about 30 cm/sec. The drifters do not show the northward flow immediately off Cape Liverpool implied in the dynamic topography of Figure 5.2.5-1(a), nor do they, with one exception, move as far east as suggested by the dynamic topography. In both Figures 5.2.5-9(b) and (c), the data is very sparse, averaging about 1 position per day. Comparison of Figure 5.2.5-9(c) with the dynamic topography in Figure 5.2.5-1(c) does show similarities, however. The drifters move further offshore as they travel down the Bylot Island coast, and turn in toward the mouth of Pond Inlet about 60 km east of Cape Burney. This pattern closely follows the flow outlined in the dynamic topography, where a meander centred approximately 40 km east of Cape Burney is shown. The dynamic topography shows surface speeds (relative to the 300 dbar reference level) of 45 cm/sec in the current down the coast and around the meander. The drifters showed average velocities between 50 and 55 cm/sec in the current along the coast, and speeds of 26 to 45 cm/sec where they turned inshore toward Pond Inlet.

The only data obtained in this zone in 1977 was the track of one drift buoy, number 1066, which passed through the area between October 24 and November 1, 1977. Its track is shown in Figure 5.2.5-10, taken from Fissel and Marko (1978). This track, although an isolated example, is similar to many seen in 1978 and 1979. As in many instances in 1978 and 1979, it travels east, away from the coast at Cape Liverpool, moving south and east until it reaches a point 60 km northeast of Cape Burney, whereupon it curves in toward the mouth of Pond Inlet.



(a) August 3 - 30, 1978

(b) August 30 - Sept. 15, 1978



(c) Sept. 15 - Oct. 20, 1978

Figure 5.2.5-9(a), (b) & (c): Drifter tracks through area east of Bylot Island in 1978.

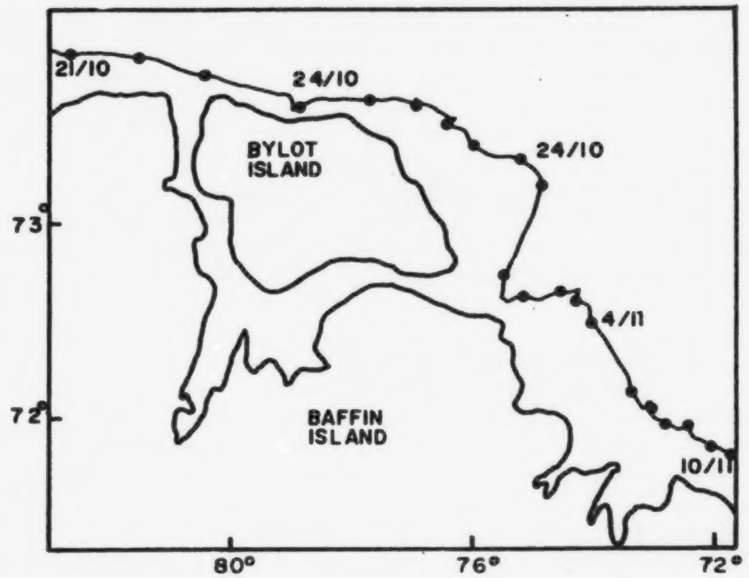

21/10
24/10
24/10
4/11
10/11
BYLOT ISLAND
BAFFIN ISLAND
73°
72°
80°
76°
72°

Figure 5.2.5-10: Track of drifter 1066 past Bylot Island in 1977.

Table 5.2.5-1

Characteristics of Eddies Observed in 1979

Drifter	Date	Sense	Approx. Position of centre (lat., long.) deg.		Diameter (km)	Avg. Speed of drifter (km/day) computed from successive positions	Distance offshore (km)	Period (hrs)
1958	13-15 Sept.	anticyclonic	73.519,	76.784	23±3	47±8	17	35±1
	16-18 Sept.	anticyclonic	73.194,	75.532	18±1	24±9	25	57±1
	18-20 Sept.	anticyclonic	73.194,	75.532	11±6	19±9	25	48±1
1959	28-29 Sept.	anticyclonic	73.566,	76.863	15±1	29±12	16	42±1
	1-2 Oct.	anticyclonic	73.290,	76.448	10±5	15±5	10	56±1
1962	11-13 Oct.	cyclonic	73.473,	74.528	8±2	10±3	75	52±1
	16-19 Oct.	cyclonic	73.753,	75.311	10±1	11±9	65	78±3
1963	6-10 Oct.	anticyclonic	72.808,	75.492	22±1	22±3	23	92±5
1968	13-14 Sept.	anticyclonic	73.556,	76.799	17±3	40±20	17	34±1
	14-15 Sept.	anticyclonic	73.481,	76.162	16±2	36±6	20	31±1
	16-18 Sept.	anticyclonic	73.229,	75.514	28±2	43±11	28	26±1
	19-20 Sept.	anticyclonic	73.191,	75.305	12±5	24±9	32	44±1
1980	13-15 Oct.	anticyclonic	73.252,	75.862	29±4	39±18	25	55±2
	22-24 Oct.	anticyclonic	72.790,	74.447	11±2	14±4	53	74±2
	25-27 Oct.	anticyclonic	72.778,	74.153	9±1	14±4	63	48±1
1982	11-13 Oct.	cyclonic	73.506,	74.518	7±1	9±6	75	57±2
1983	2-3 Oct.	cyclonic	73.262,	75.019	7±1	12±5	75	42±2

Observations of Eddies East of Bylot Island

In addition to the large scale gyres and meander-like features of the flow east of Bylot Island, smaller scale eddies are often observed in drifter tracks, superimposed on the net flow.

These eddies are observed from time to time between the main axis of the southeastward flow off the Bylot Island coast and the coast itself. Figure 5.2.5-6(b) shows several of these eddies with the 1979 drifters. The eddies, being relatively small and close to shore, were not resolved by the CTD data in either year. The radar camp maintained at Cape Fanshawe in 1978 by NORDCO Ltd. found loops in the paths of icebergs, observed from the camp, which suggested the presence of eddies off Cape Fanshawe. Although iceberg movements are driven by deeper flows and winds in addition to the surface circulation, in the absence of any other data capable of resolving these flow features, the iceberg tracks will be used as the best source of information for 1978 surface circulation in this region.

Since the drifter tracks collected in 1979 constitute the best data set, they will be treated first. Figure 5.2.5-11 shows an example of the eddies, in the track of drifter 1958. Table 5.2.5-1 summarizes the characteristics of all the eddies observed during 1979 in the tracks of the drifters passing east of Bylot Island.

The remaining drifters passed through the zone without encountering any eddies. Table 5.2.5-2 lists them and the dates between which they passed through the area.

Table 5.2.5-2

Summer 1979 drifter tracks which showed no eddy motion in the area east of Bylot Island.

Drifter No.	Dates
1961	11-15 October
1962	5- 9 October
1971	4- 6 October
1973	9-12 September
1974	17-19 August
1976	18-21 September
1977	28 September-2 October
1982	30 September-3 October

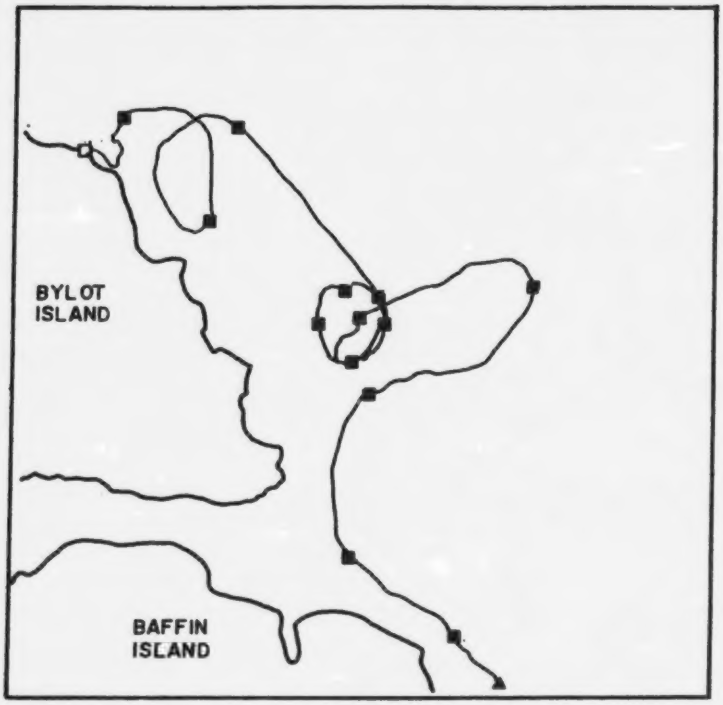

BYLOT
ISLAND
BAFFIN
ISLAND

Figure 5.2.5-11: Track of drifter 1958 from September 12-24, 1979.

Examination of Table 5.2.5-1 reveals that the observed eddies divide naturally into two classes: anticyclonic eddies within 35 km of the Bylot Island coast, and eddies more than 50 km offshore, which may have either sense of rotation. The 11 anticyclonic eddies detected in the coastal band have a mean diameter of 18±7 km, and a mean period (i.e., the time taken for the drifter to complete the circuit) of 46± 15 hours. The mean diameter for all six eddies observed more than 50 km offshore is 10±3 km, and their mean period is 59±14 hours. The six offshore eddies were divided into 4 cyclonic and 2 anticyclonic; the cyclonic eddies had a mean diameter of 8±1 km and mean period of 57±15 hours, while the two anticyclonic eddies had a mean diameter of 14±2 km and a mean period of 61±18 hours. Clearly the eddies formed within 35 km of the coast, and those formed more than 50 km offshore are different in character. Those near the shore are always anticyclonic, and are larger in scale and rotate more quickly than those observed offshore, which may be of either sense.

Figures 5.2.5-12(a), (b) and (c) show the locations and shapes of the eddies observed in 1979, together with any nearly simultaneous tracks of other drifters in the area. Figure 5.2.5-12a shows two concentrations of eddies, one off Cape Fanshawe, the other off Cape Burney, which were observed between September 13 and 16 and September 17 and 20, 1979, respectively. Both sets of eddies seem to be located between the coast and an offshore current suggested by the track of drifter 1976 between September 18 and 21. The southern eddy is apparently at the centre of a large anticyclonic meander. Note that the southern eddy apparently did not exist one week previously when drifter 1973 passed through the location of its centre without any rotational motion. Figure 5.2.5-12(b) shows drifter 1977 passing through the same location September 30 (ten days after the observation of the eddy) also with no evidence of rotational motion. Apparently the eddy existed in that location for less than two weeks. The remainder of Figure 5.2.5-12(b) shows anticyclonic eddies off Cape Fanshawe September 28-29, off Cape Walter Bathurst October 1-3, and off Cape Graham Moore Octobner 6-9. Again, these eddies occupy a zone between the shore and a southeasterly flow paralleling the coast approximately 30 km offshore. Figure 5.2.5-12(c) shows the last set of eddies to be observed. The two small eddies off the mouth of Pond Inlet are smaller in scale and of longer period than the eddies observed close to the Bylot Island coast, and have therefore been classified with the other offshore eddies. The anti-cyclonic eddy off Cape Burney appears to fit the pattern observed above, i.e. an anticyclonic eddy occurring between the coast and the southeasterly flow about 35 km offshore.

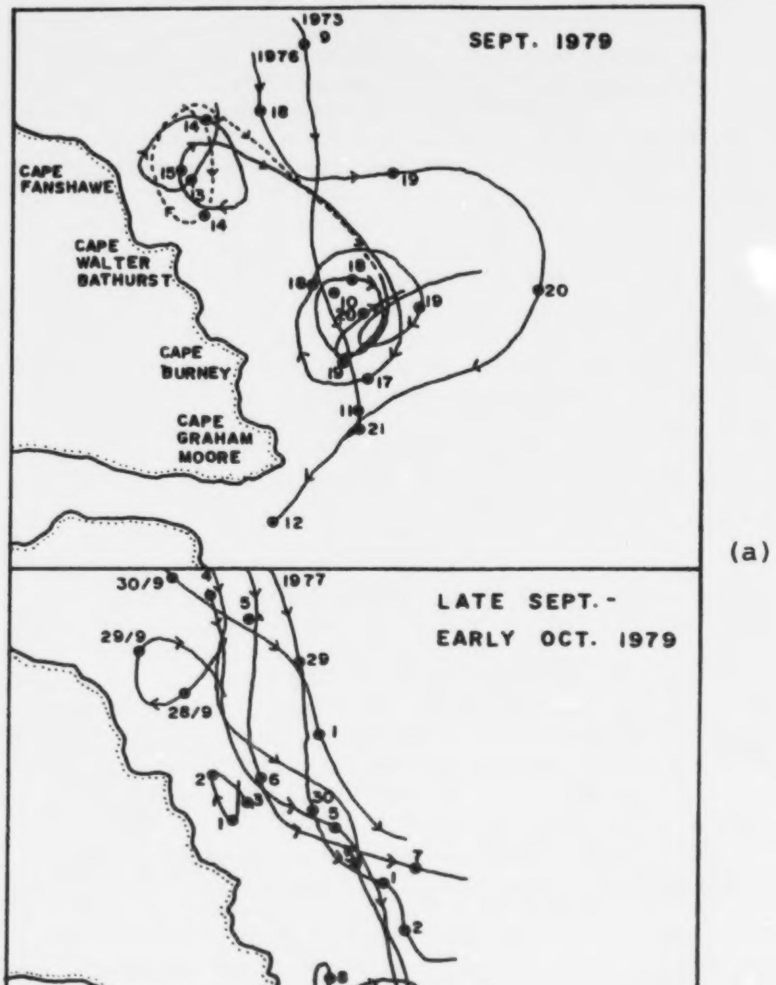

SEPT. 1979
1973
9
1976
18
14
15
13
14
CAPE FANSHAWE
CAPE WALTER BATHURST
CAPE BURNEY
CAPE GRAHAM MOORE
19
16
18
10
20
19
20
19
17
11
21
12
(a)
LATE SEPT.-
EARLY OCT. 1979
30/9
1977
5
29/9
29
28/9
1
2
6
3
30
5
1
7
1
2
8
9
7
6
6
(b)
MID-LATE
OCT. 1979
14
15
14
13
15
16
25
22
23
26
(c)

Figure 5.2.5-12(a), (b)&(c): The locations and shapes of eddies as revealed by 1979 drifter tracks.

Similar patterns were observed in the drift of icebergs tracked from the Cape Fanshawe radar camp in 1978 (NORDCO, 1979). The icebergs described loops, always in an anticyclonic sense, centred about 25 km off Cape Fanshawe. Typical diameters and periods are given as 22 km and 60 hours and 8 km and 30 hours. The loops were observed intermittently throughout the summer, but more frequently during the first three weeks of August. Since the relative importance of the forces controlling iceberg drift is not fully understood, these observations should be taken only as supporting evidence for the existence of the eddies, and not as definitive proof.

There is evidence for the existence, in both 1978 and 1979, of anticyclonic eddies along the Bylot Island coast, typically 20 km in diameter. Although they may appear anywhere along the coast, favoured locations are at Cape Fanshawe and Cape Burney.

Summary

The region east of Bylot Island is an area where both large and small-scale perturbations occur in the Baffin Current. The current on leaving Lancaster Sound usually becomes detached from the coast at Cape Liverpool. The direction of flow at Cape Liverpool varies from southeasterly, along the coastline, to northeast with the most common direction being east. Further downstream the current flows to the southeast, parallel to the eastern Bylot Island coastline, but usually 30 to 50 km offshore. This pattern is frequently distorted by large-scale (60 to 70 km) meanders, which sometimes are associated with northerly counter-currents east of the south-flowing current. Smaller scale eddies can occur in this offshore zone with rotation in either sense and diameters of 7 to 16 km. Between the coast and the southeasterly current, anticyclonic eddies of approximately 20 km diameter are frequently seen. Their rotation period is between 40 and 50 hours, on average. Smaller eddies are observed outside this zone, which may be of either sense of rotation, and have longer periods (55 to 65 hours).

The southeasterly flow turns westward, toward the mouth of Pond Inlet once it reaches the southern end of Bylot Island. This turning of the flow generally coincides with the position of a seamount located at the southeastern limit of the Bylot Island shelf which suggests that the shelf and seamount may exert some topographic control over the current.

5.2.6 East of Baffin Island

The circulation off the east coast of Baffin Island is dominated by the southeasterly Baffin current. Important and temporal and spatial variations occur in the southeasterly flows. Large gradients in the local bathymetry and the time-varying ice conditions may be important in determining local circulation patterns.

Bathymetry and Ice Conditions

The western boundary of Baffin Bay is characterized by a shallow (200 m) continental shelf, extending as far as 50 km offshore. Beyond the shelf is the continental slope, where the water depths increase from 200 m up to 2000 m over distances of typically 50 km. This slope region forms the western boundary of a deep (188 to 2400 m) and relatively flat basin (see Figure 5.2.6-1). The northern extremity of the Basin is aligned due north at an angle of about 60° to the generally northwestward orientation of the Baffin Island coastline. As a result, a relatively flat area is found due east of the entrance to Pond Inlet, with depths of 700 to 900 m between the converging continental slope and sloped boundary of the deep basin.

The continental shelf is broken into individual segments by deep underwater canyons extending from the inlets of Baffin Island out to the continental slope. Pond Inlet may be considered as the northernmost such protrusion with others occurring off Buchan Gulf, Scott Inlet and fiords opening into Home Bay. Our present knowledge of the bathymetry of individual shelf segments is sketchy at best. There is evidence of considerable irregularities in the bathymetry of the shelves, including the presence of large shoals. The most prominent of these are Hecla and Griper Banks located over 10.5 km off Remote Peninsula immediately to the south of Scott Inlet. These banks, 25 km in length, are the site of many iceberg groundings. Other shoal areas along the continental shelves have been reported but have yet to be sounded in detail.

Ice conditions are generally more severe in the western part of Baffin Bay along the coastline of Baffin Island. Open water appears to the north and the south prior to clearing in this region. Normally the sea-ice lingers in the region through the month of August. Coastline areas, particularly in Home Bay, are the last areas to open. Freeze-up begins in late October and early November, limiting the open water period to little more than two months on average.

Drifter-deduced Circulation

Twelve of the drifters deployed further to the north in 1978 and 1979 were tracked southwards of Pond Inlet in 1979, while five were followed through the region in the previous year. One 1978 drifter (number 370) survived the winter of 1978/1979 at a location 120 km north of Broughton Island and after ice break-up in early August, continued its southward journey, passing Cape Dyer in late August 1979.

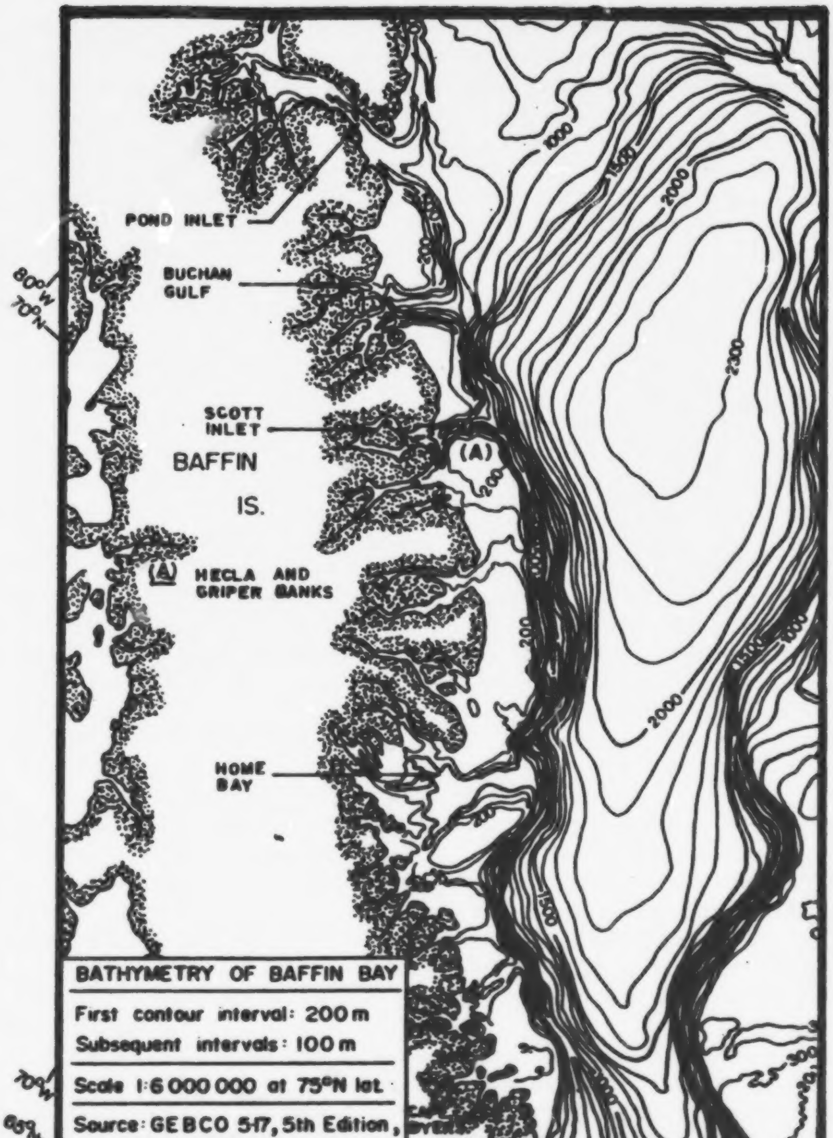

POND INLET
BUCHAN GULF
SCOTT INLET
BAFFIN IS.
(A)
(A) HECLA AND GRIPER BANKS
HOME BAY
1000
1500
2000
2300
200
2000
1000
BATHYMETRY OF BAFFIN BAY
First contour interval: 200 m
Subsequent intervals: 100 m
Scale 1:6 000 000 at 75°N lat.
Source: GEBCO 5-17, 5th Edition, Aug. 1979; I.H.O.
80°W
70°N
70°W
65°N
65°N
60°W

Figure 5.2.6-1: Bathymetry off Baffin Bay off the east coast of Baffin Island.

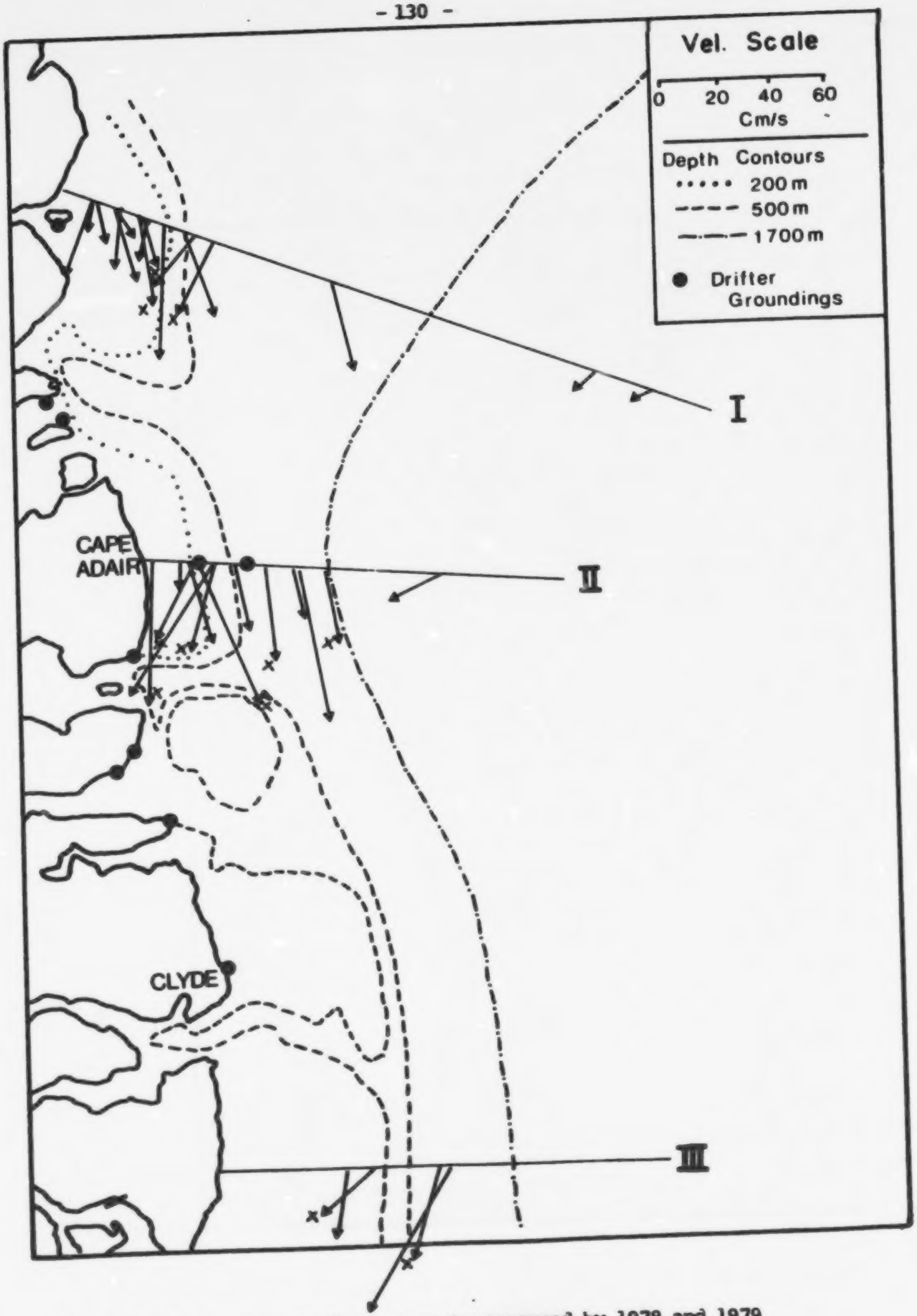

Vel. Scale
0
20
40
60
Cm/s
Depth Contours
200 m
500 m
1700 m
Drifter Groundings
I
II
III
CAPE ADAIR
CLYDE

Figure 5.2.6-2: Near surface currents measured by 1978 and 1979 drifters through three sections east of Baffin Island. Those velocities marked with a (*) were measured during the formation of new ice.

The drifter velocities were computed at three sections extending outwards from the northern and central portions of Baffin Island as shown in Figure 5.2.6-2. Some of these velocities were measured from drifters movifng through newly-forming ice (indicated by a *) which may have reduced their speeds. Sixteen drifters crossed the northern section (I) with a median velocity of 22 cm/s, ranging from 4 cm/s to 49 cm/s. Of these, nine were moving over the shelf while four were over the continental slope and three were well off-shore over a gently sloping bottom. The relative abundance of drifter crossings over the shelf, as compared to the slope region, appears to result from a tendency of the drifters moving out of the mouth of Pond Inlet to turn to the right into the shallower water of the shelf. However, those drifters located over the continental slope or over the outer edge of the shelf showed a tendency to move faster than those further inshore or offshore in more gently sloping areas. This can be seen clearly in the vector averaged velocities computed over grid areas with dimensions of 0.1667 degrees of latitude (18 km) and 0.5 degrees of longitude (18 km at 71° latitude) as shown in Figure 5.2.6-3.

The difference between the flow speed over the shelf and the slope is more pronounced for section II lying offshore from Cape Adair. Here the median velocity is 30 cm/s ranging from a minimum of 8 cm/s to a maximum of 57 cm/s. An examination of the averaged velocities computed for grids in the vicinity of section II shows that for those grids on the shelf, the average velocities range from 12 to 20 cm/s as compared to a range of 24 to 30 cm/s for grids located exclusively over the slope. The highest velocity of a drifter passing through line II (57 cm/s) was measured over the continental slope. In addition to the enhanced difference between slope and shelf current speeds, more drifters were located in the slope zone in section II. This was a result of the offshore movement of four drifters (1959, 1963, 1976 and 1980) as they approached the northern flank of the section II shelf. Rather than movifng into the markedly shallower shelf waters, their movements roughly paralleled that of the local bathymetry, moving offshore over the continental slope region. This result implies that the local topography may be of importance in influencing the course of the Baffin current as suggested by Muench (1971). He argued that the tendency of currents extending to the bottom to conserve potential vorticity, a depth-dependente quantity, could be an important factor. However, this is difficult to assess quantitatively due to uncertainties in the magnitude of the local relative vorticity. Certainly, the topographic influence is not the dominant factor at all times, as can be seen by the strong movement into the shelf at section I and the movement of two drifters on the shelf at section II.

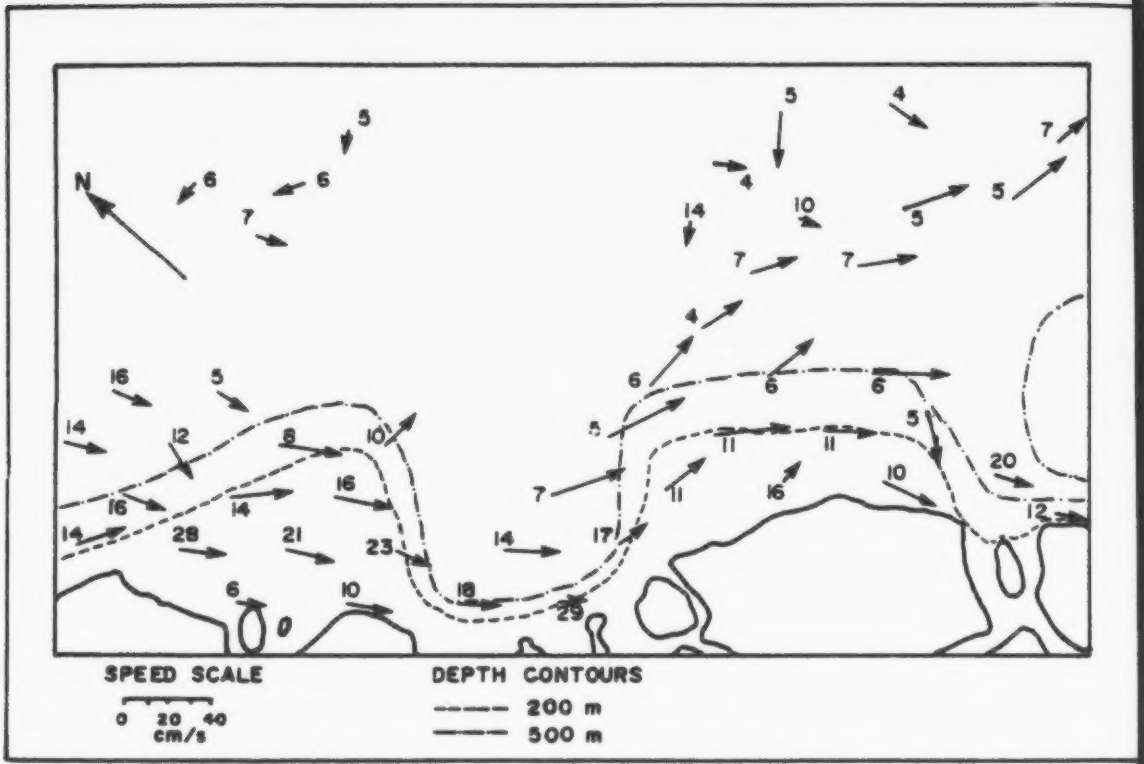

N
SPEED SCALE
0 20 40
cm/s
DEPTH CONTOURS
200 m
500 m

Figure 5.2.6-3: Averaged velocities from 1979 drifter data off the east coast of Baffin Island.

Between sections I and III, a total of eight drifters ran aground at sites shown in Figure 5.2.3-2. In addition, another three drifters failed at offshore locations, reducing the number of drifter crossings of section III to four. The surviving drifters passed through the section well offshore with a median velocity of 29 cm/s, ranging from a minimum of 20 cm/s to a maximum of 59 cm/s. The drifter passages were located either on the continental slope (2) or on the outer edge of the shelf (2).

All five drifters which entered the area east of Baffin Island at distances of 100 km or more offshore from the mouth of Pond Inlet, moved closer to shore over the continental slope prior to reaching section III. Two of these failed shortly after passing section I at distances of 43 km and 76 km from shore, while the other three all passed through section III. This convergence of the flows beyond 100 km of shore with the flows nearer the coast noted between setions I and III parallels the convergence of the more gently sloping northwest side of the deep basin in central Baffin Bay with the continental slope off Baffin Island.

South of section III, from Home Bay to Cape Dyer, the drifter data is limited in quantity. In Figure 5.2.6-4, the tracks of the surviving drifters are superimposed upon the smooted bathymetry of the area. In Home Bay itself, two drifters (466 and 1975) appeared to follow the slope into the deep central portion of Home Bay, whereupon both failed. Two others (1979 and 1980) passed further offshore of Home Bay and remained in the slope area making steady southward progress; their mean velocities from passing northern Home Bay to Cape Dyer were 33 and 24 cm/s respectively with a maximum daily movement of 62 cm/s. Drifter 370, which had been locked into the ice since the previous winter, moved to the south some distance further offshore once the local ice had broken up. However, its movements were constrained by the extensive sea-ice remaining closer to shore which may explain both the greater distances offshore and the somewhat reduced net speed of 19 cm/s.

Circulation Patterns Deduced from CTD Data

As part of the present study, CTD surveys along the east coast of Baffin Island were carried out on several occasions in 1978 and 1979. From the 1979 data, the baroclinic portion of the surface circulation was determined from computed dynamic height anomalies relative to a depth of 300 m as shown in Figure 5.2.6-5 for the three most complete data sets. The choice of a 300 m reference level limits the circulation patterns of Figure 5.2.6-5 to areas over the continental slope and the deep, central basin of Baffin Bay since the edge of the continental shelf area is generally within the 200 m isobath. The use of a shallow reference level is avoided since unacceptably large errors may result from the reduced validity of the assumed geostrophic balance expected in shallow areas; an as example, the spatial scales of the circulation may be much shorter, enhancing the inertial terms in the equation of motion.

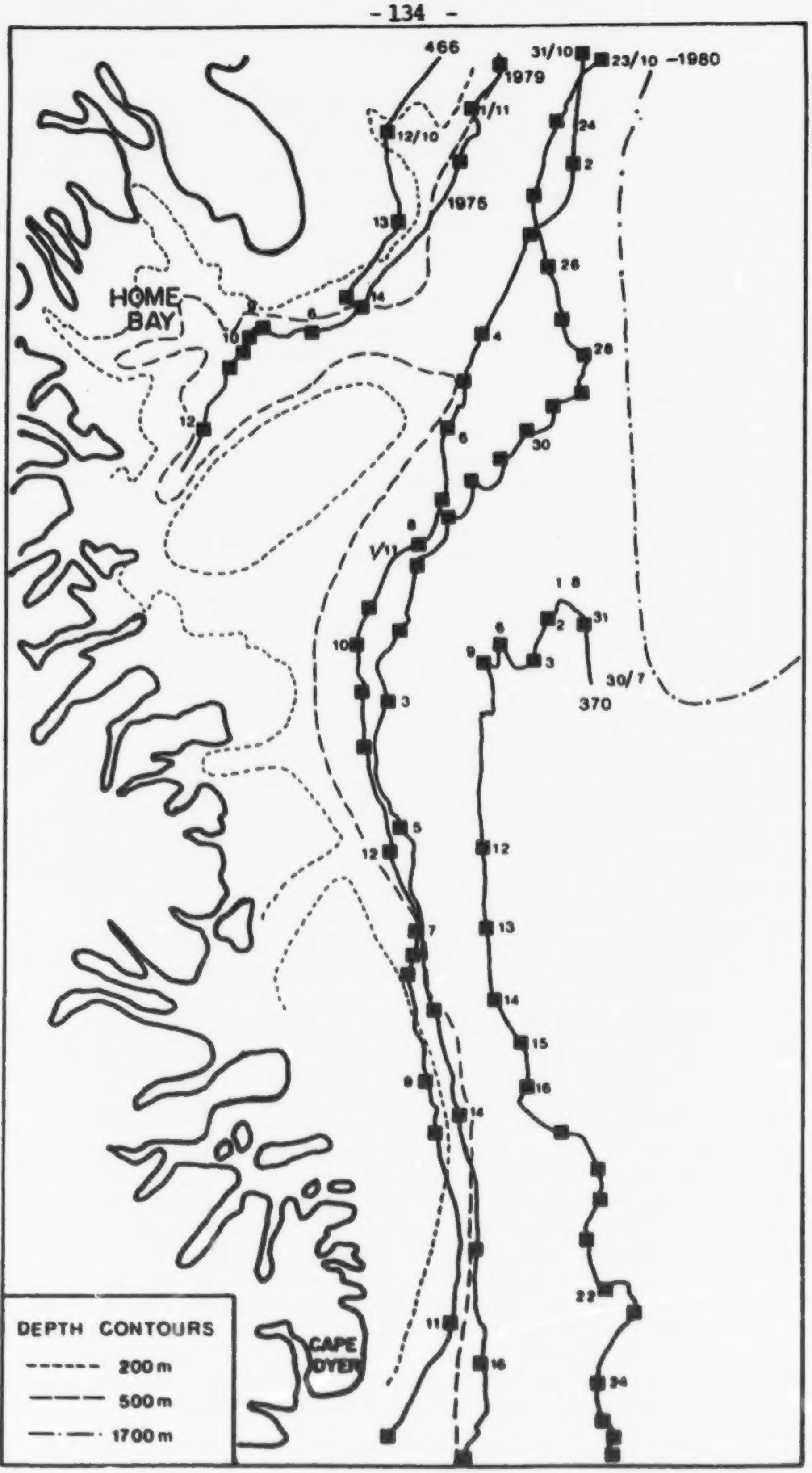

466
1979
31/10
23/10 –1980
1/11
12/10
24
2
1975
13
26
HOME BAY
14
6
10
4
28
12
6
30
8
1/11
1 8
6
2
31
9
3
30/7
370
10
3
5
12
12
7
13
14
15
16
9
14
22
11
16
24
CAPE DYER
DEPTH CONTOURS
200 m
500 m
1700 m

Figure 5.2.6-4: Drifter tracks off the south-east coast of Baffin Island along with simplified bathymetry.

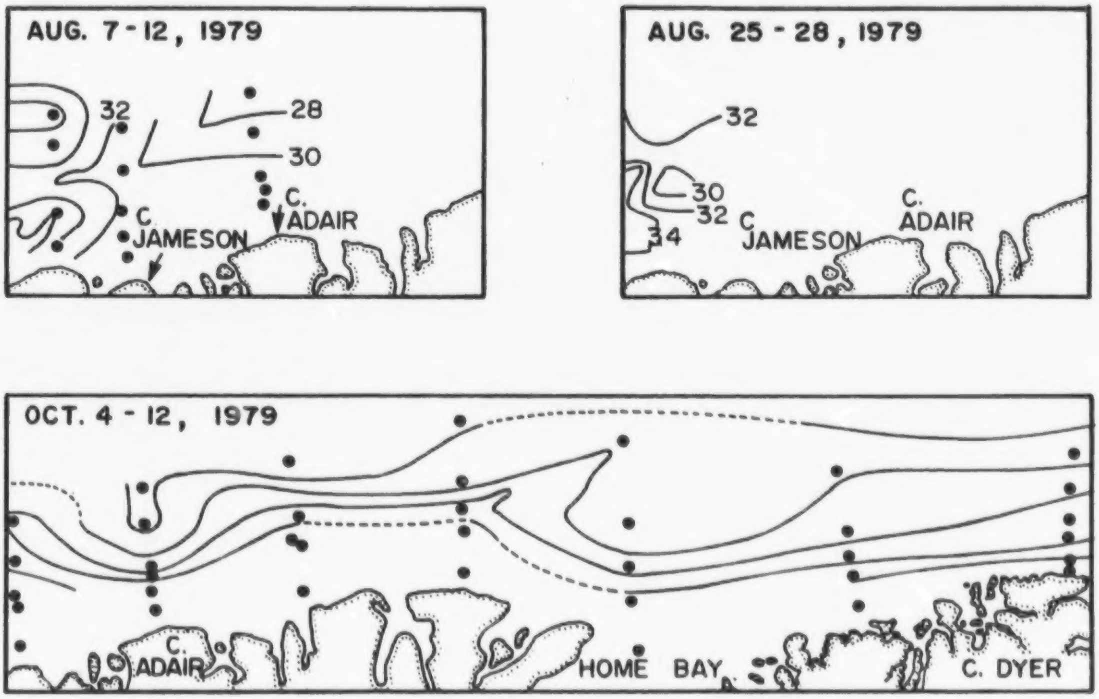

AUG. 7 - 12, 1979
32
28
30
C
JAMESON
C.
ADAIR
AUG. 25 - 28, 1979
32
30
32
34
C
JAMESON
C.
ADAIR
OCT. 4 - 12, 1979
C.
ADAIR
HOME BAY
C. DYER

Figure 5.2.6-5: Dynamic topography of the surface relative to 300 dbar from 1979 CTD Data.

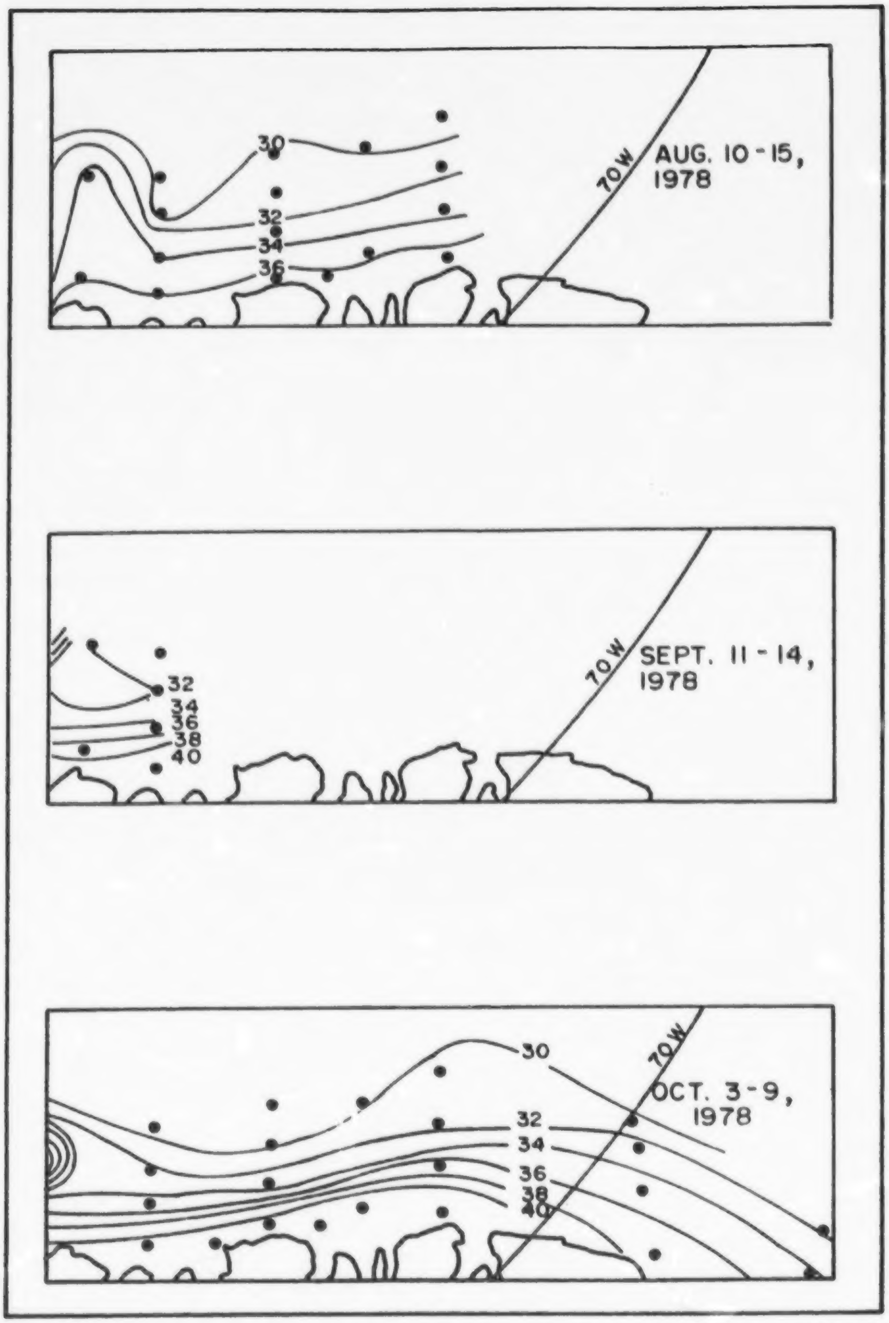

30
32
34
36
70W
AUG. 10 - 15,
1978
32
34
36
38
40
70W
SEPT. 11 - 14,
1978
30
32
34
36
38
40
70W
OCT. 3 - 9,
1978

Figure 5.2.6-6: Dynamic topography of the relative to 300 dbars from 1978 CTD data.

The CTD-derived circulation is stronger on the inshore portion of the continental slope where the depth gradients are largest as compared to the more gently sloping offshore portions. This is evident to varying degrees in every cross-section of CTD stations extending outwards off Baffin Island from Cape Jameson to Cape Dyer.

The 1978 dynamic topographies (Figure 5.2.6-6) showed an increase in the surface speed relative to 300 dbar throughout the summer season. The speed in the current core off Cape Jameson was 12 cm/sec on August 12 - 17, 1978, 26 cm/sec on September 12, and 26 cm/sec on October 3. In the last instance further south (off Cape Adair on October 4) current speeds were up to 35 cm/sec. In 1979 the flow at Cape Jameson showed a tendency to decrease: on August 29 the core speed was 19 cm/sec, while on October 5 it was 10 cm/sec. An earlier measurement at Cape Jameson (August 10 - 11) showed no organized south-easterly flow at all. The maximum speed in 1979 was found off Cape Adair on October 5, at 29 cm/sec.

The weaker outer portion of the Baffin current appears to meander from one cross-section to the next as to distance offshore. This is apparent in the shape of the 3.0 contour of dynamic height anomaly: for the August 10 - 15, 1978 CTD data, this contour was further offshore at Cape Adair than at the adjacent sections, while on Oct. 3 - 9, 1978 and Oct. 4 - 12, 1979 the contour was closer to shore than at adjacent sections. Scale lengths of 60 - 100 km along the stream and 35 to 40 km across the stream are suggested from the CTD circulation patterns. However, since the apparent along-stream scale length is comparable to the spacing of the CTD sections, the meanders may not be adequately resolved; the actual scale lengths could be shorter. Further evidence of meander-like features is provided in the tracks of drifters 1975, 1979 and 1980, all of which followed offshore trajectories in water depths exceeding 1000 m (see Figure 5.2.6-7). The meander-like feature in each track varies considerably as to location, shape and scale, with the latter ranging from 40 to 120 km. The drifter speeds measured in the meander patterns vary as well; for drifters 1975 and 1979, the typical speeds were 10 cm/s and never more then 20 cm/s while drifter 1980 reached speeds of 40 cm/s in its offshore excursion. The variability of these limited observations indicates that a more detailed data base is required to clarify variations in the deep-water circulation east of Baffin Island.

The presence of fresher water measured near the surface at CTD stations on the shelf and slope suggests that fresh-water input from land runoff and sea-ice melt may be, at times, providing a baroclinic driving mechanism for the southward circulation. Surface salinities as low as 30.0 parts per thousand were measured at stations close to shore (12 km or more), compared to the surface

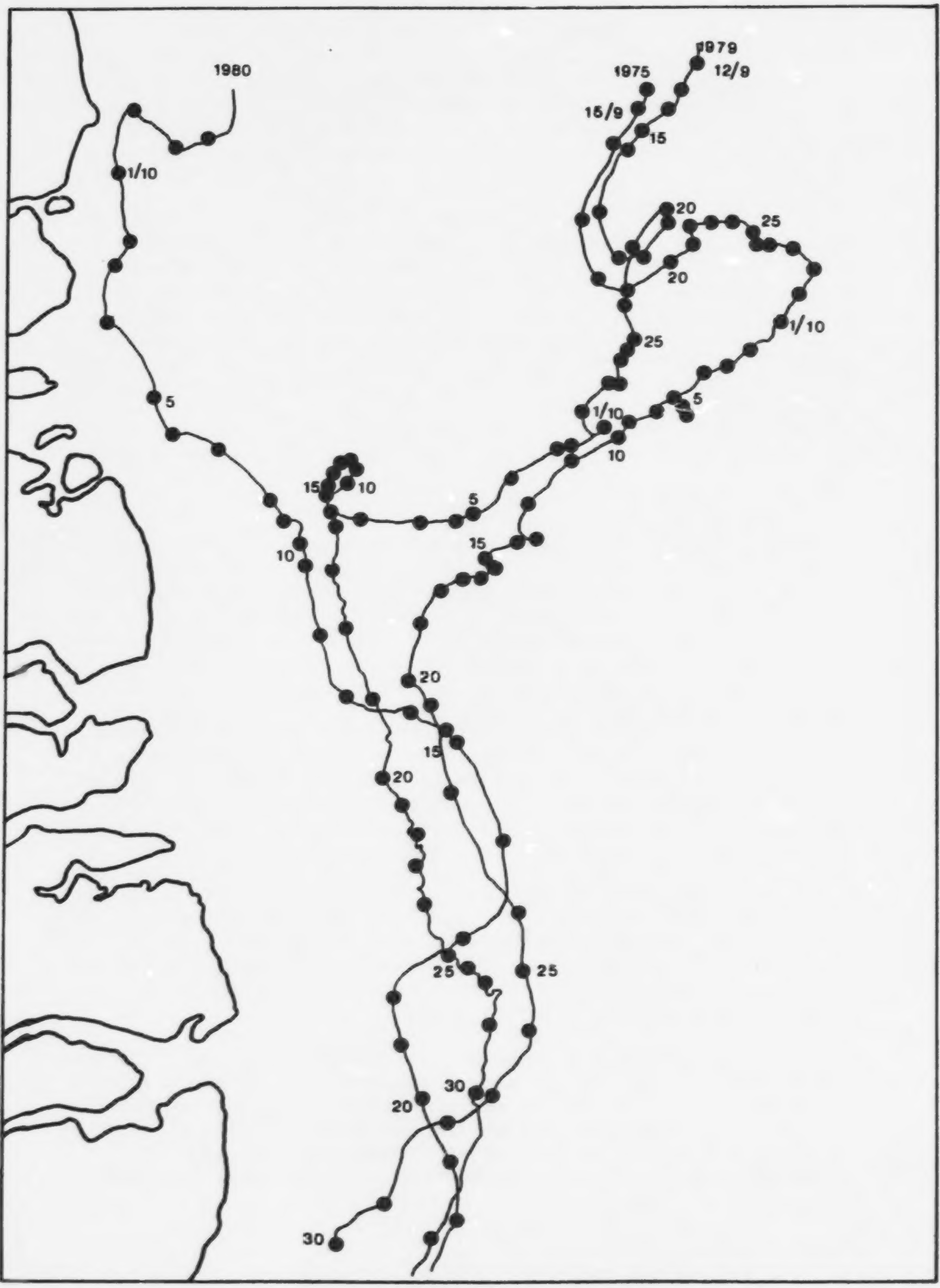

1980
1975
1979
12/9
15/9
15
1/10
20
25
20
1/10
25
5
1/10
10
5
15
10
5
15
10
20
15
20
25
25
30
20
30

Figure 5.2.6-7: Tracks of drifters 1975, 1979 and 1980 located well offshore in the summer of 1979.

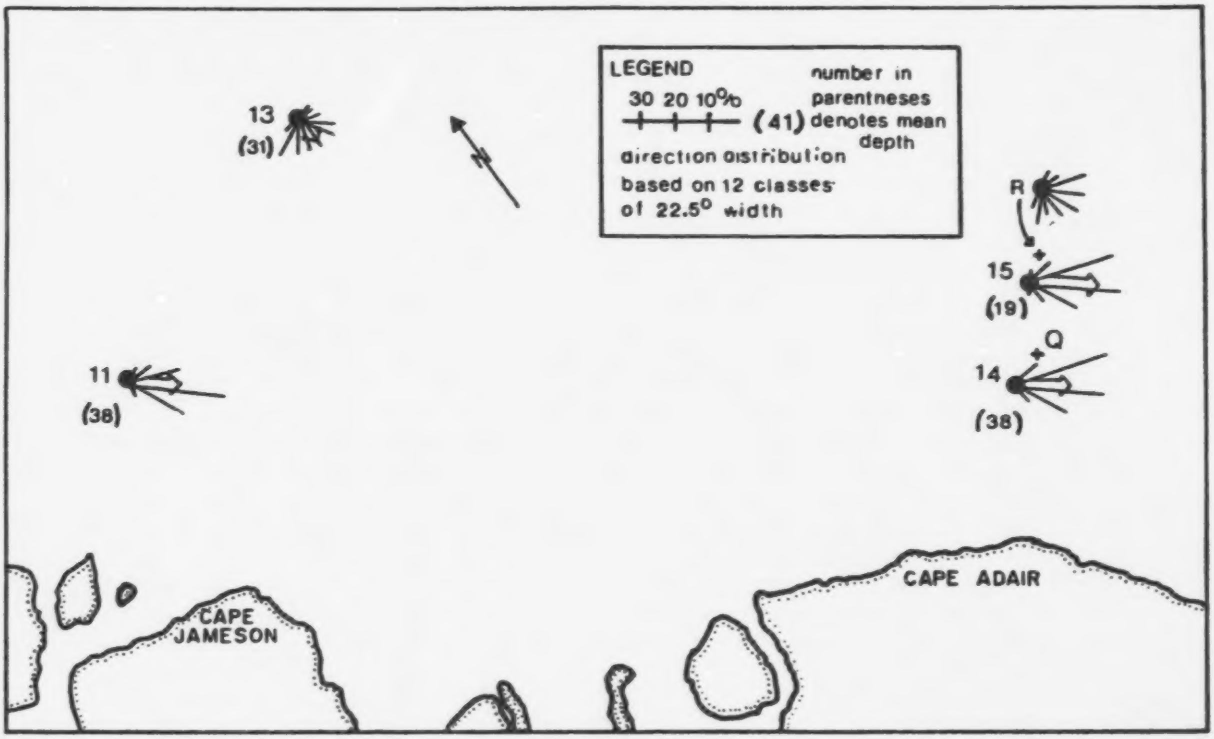

LEGEND
30 20 10%
(41)
number in parentheses denotes mean depth
direction distribution based on 12 classes of 22.5° width
13
(31)
N
R
15
(19)
Q
14
(38)
11
(38)
CAPE JAMESON
CAPE ADAIR

Figure 5.2.6-8: The directional distribution of current meter data at nominal depths of 35 m located off the east coast of Baffin Island, August - September, 1978.

salinities of 32.0 parts per thousand or more usually measured well offshore. As a result of the local freshwater input, a horizontal density gradient is produced. Assuming that a simple geostrophic balance results, a southward current is required to producee a Coriolis force which balances the internal pressure gradient due to the density gradient. The strength of the resulting current would vary according to rate of freshwater input, the extent of its dilution with sea water both as to depth and distance offshore and other factors. Thus, it is difficult to estimate the magnitude of these currents without more information. Nevertheless, simple calculations indicate that this driving mechanism could be of importance in local areas and at times of large freshwater inputs.

Current Meter Data

Four 1978 current meter moorings and two 1979 current meter moorings provide time series current data, useful in delineating the temporal variations of the circulation. The 1978 moorings were located in pairs along the sections I and II used in the discussions of the drifter data. Station 11 was located on the shelf, only 10 km from its outer edge, while station 13 was located on the slope offshore of the steepest zone. Stations 14 and 15 were both located on the continental slope off Cape Adair with Station 14 only 2 km past the shelf edge.

The averaged velocities at all stations are to the southeast, aligned within 20 degrees of the direction of the local topography (see Figure 5.2.6-8 and Table 5.2.6-1). The directional distribution shown in Figure 5.2.6-8 reveals steadier flows at stations 14 and 15 located on the shelf itself as compared to station 11 and particularly station 13 located at sites of lower depth gradients. Following removal of the tidal, inertial and higher frequency variatioans by means of a low pass digital filter (half of the amplitude passed at a period of 3 days), no reversals were found to occur in the low-passed, 35 m currents at stations 14 and 15. The same procedure applied to the data from stations 11 and 13 revealed one period of reversed flows with a duration of 3 days or more at station 11 and two such reversals at station 13. At all sites, the temporal variations of the uppermost current meter data were characterized by synoptic variations over a wide range of time scales from three days to several periods of ten days.

Table 5.2.6-1

Statistics of Uppermost Current Meter Measurements off the East Coast of Baffin Island

Station	Mean Depth (m)	Record Length (days)	Average Speed (cm/s)	Velocity Direction (°T)	Mean Speed (cm/s)	Max. Speed (cm/s)	B (%)
Nominal Depth: 35 m							
11	38	53	15.1	130	19.7	84.7	77
13	31	54	7.6	175	17.3	50.5	44
14	38	46	17.1	131	19.6	56.7	87
15	19	51	20.9	132	24.0	63.4	87
R	(35)	54	7.1	156	12.8	48.8	55
Nominal Depth: 125 and 250 m							
11	126	47	4.7	134	8.5	40.4	55
13	254	54	4.8	180	7.8	27.8	62
14	126	52	8.4	139	10.2	32.6	82
15	234	51	10.9	126	11.4	37.6	96
Q	163	54	2.6	114	5.8	19.4	45
R	(250)	54	5.5	130	8.5	48.3	65
Nominal Depth: 500							
13	507	54	3.5	168	7.2	24.4	49
15	479	51	9.6	125	10.4	34.0	92
R	485	54	6.7	127	7.6	29.2	88
October 1978 - July 1979							
13	31	309	5.7	167	8.1	43.2	70
13	263	309	3.1	179	6.6	23.2	47
13	(500)	305	2.2	201	5.7	26.4	39
13	748	309	2.8	23	5.4	22.2	52

Based on the current meter data, the southeastward Baffin Current appears to extend from the surface to depths of at least 500 m. At station 14, and nearby station R, operational in 1978 and 1979 respectively, a steady southeasterly flow was measured at 500 m. At station 13, the speed signal failed on the current meter at 750 m depth in the August to September 1978 measurement period. Data at this site and depth is available from October 1978 to July 1979. The vector average velocity was 2.8 cm/s with a net direction of 23 degrees true. However, in the months of October, November and July, the net flow was southerly with good correlation between the low passed fluctuations in the currents at 500 m and 750 m depth. As well, 51% of the August to September 1978 directional data at 750 m fell between southeasterly and southwesterly. Thus, it seems likely that the Baffin Current extends to depths of 750 m during the summer and autumn for considerable periods of time.

The strength of the Baffin current measured at stations Q and R diminished in the summer of 1979 as compared to the previous summer at nearby stations 14 and 15. The 35 m vector averaged velocity at R was only 7.1 cm/s as compared to 20.9 cm/s measured at station 15, located 3 km to the southwest. Similar reductions were observed at 250 and 500 m depth. At station Q, located 5 km east of station 14, the upper current meter failed; however, the currents at a nominal depth of 125 m were only 5.5 cm/s as compared to 8.4 cm/s at station 14.

Summary

The southeasterly Baffin Current dominates the water movements of western Baffin Bay along the length of the coastline of Baffin Island. South to easterly flows were measured over a wide range of distances from the coast; satellite-tracked drifters were observed moving to the southeast from 2 km to 230 km offshore. The core of the current is located at the edge of the continental shelf and over the most steeply sloping portions of th continental slope. Near-surface velocities have an average value of approximately 30 cm/s in the core of the current, occasionally reaching speeds in excess of 60 cm/s. Further offshore, the velocities decrease; at the outer edge of the continental slope, typical velocities of 10 cm/s appear to prevail although occasional much larger values (up to 40 cm/s) have been measured by drifters. The offshore flow shows a tendency to meander somewhat over distances of 35 km across the flow with along-stream length scales of 40 to 120 km. The meander patterns are not permanent but vary with time and locations.

The circulation patterns are influenced by the topography along the continental shelves and slopes as demonstrated by the manner in which the core of the current follows the slope regions. On the shelves, the net flow is reduced with averaged velocities of 12 to 20 cm/s. The speeds of currents on the shelf may be considerable: the largest current measured in this region (85 cm/s) was observed at current meter station 11 located on the shelf. However, the shelf currents are more variable than those over the slope, resulting in reduced net movements.

Considerable temporal variations are evident in the currents, dominated by broad-banded, synoptic variations with periods from three days to several tens of days, associated with the Baffin Current itself. Sizeable inertial oscillations of up to 30 cm/s can occur (section 5.5) in the area. Even longer period variations in the currentes may be of importance, as suggested by the reduction, by a factor of 3, in the summer currents on the continental slope off Cape Adair, between 1978 and 1979.

5.2.7 Western and Central Lancaster Sound

Introduction

This section will be concerned with surface circulation in western and central Lancaster Sound, i.e. between Prince Leopold Island and Croker Bay. This area is west of the intrusive current described in Section 5.2.3, and is a region of quite distinct circulation. There are few current meter measurements in this region, and those that do exist were taken near the eastern boundary. Circulation patterns will be deduced chiefly from drifter data, as well as from a limited number of water mass measurements. (CTD measurements were made west of Croker Bay only once during 1979, and not at all in 1978). The satellite-tracked drifter data are from 1979, when 14 drifters passed through some portions of the area, and from 1977, when 6 drifters deployed in Barrow Strait and Lancaster Sound passed through this part of the Sound (Fissel and Marko, 1978). No drifters were released in this part of the Sound in 1978, and none entered it from the east.

Surface Circulation - Pre-1979 Results

Previous studies (Dunbar (1951), Bailey (1957), and Collin (1962)) have deduced, primarily from water-mass measurements, a complex circulation pattern is western Lancaster Sound, with both eastward and westward currents present. Figure 5.2.7-1(a) shows the 1954 surface currents presented by Bailey (1957) and Figure 5.2.7-1(b) shows the circulation pattern computed from 1956 and 1957 measurements by Collin (1962). Figure 5.2.7-1(a) shows a broad easterly flow over most of western Lancaster Sound, while Figure 5.2.7-1(b) shows a complex series of opposing easterly and westerly flows in the centre of the channel. The vector-averaged velocities of the drifters released in 1977 (Figure 5.2.7-2) also show a complex circulation in western Lancaster Sound. Fissel and Marko (1978) summarized the data as:

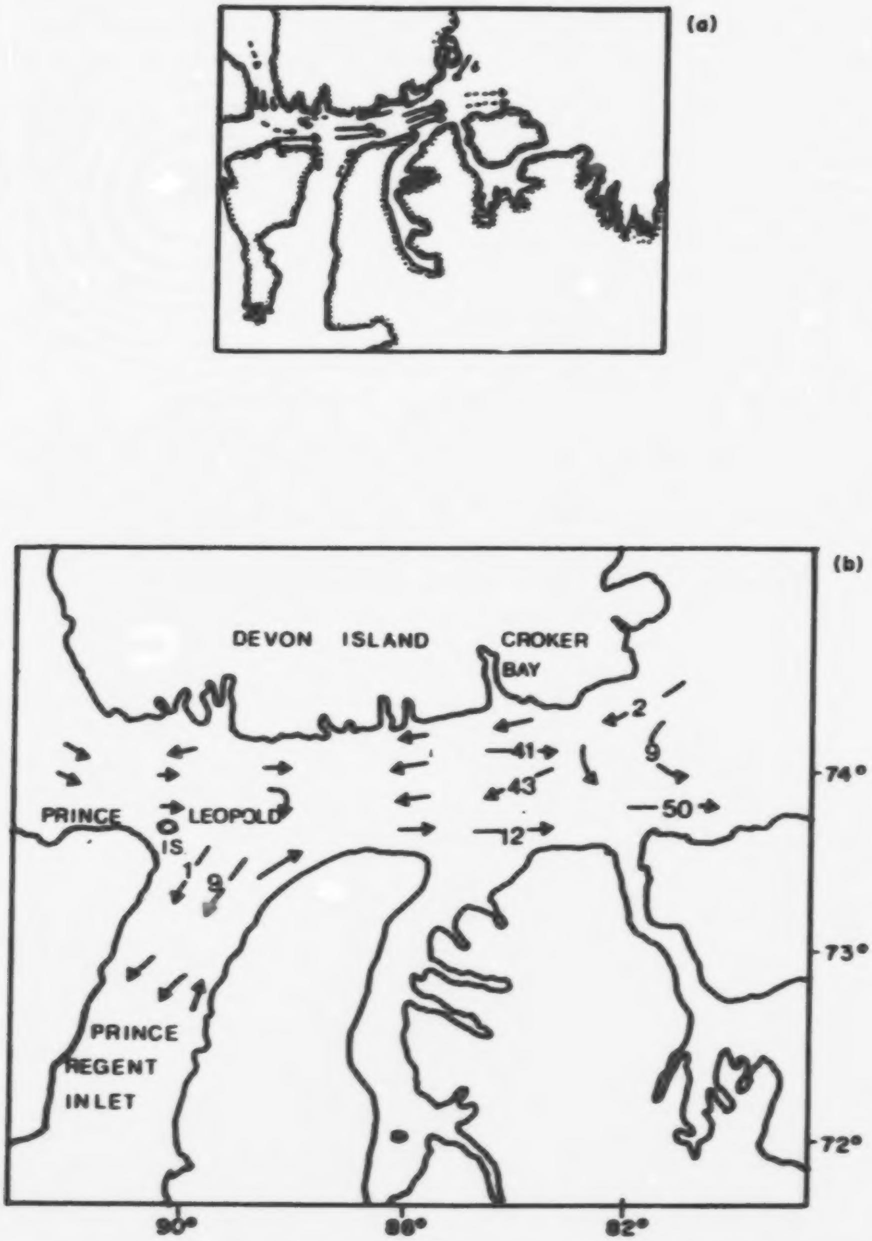

(a)
(b)
DEVON ISLAND
CROKER BAY
PRINCE LEOPOLD IS
PRINCE REGENT INLET
2
9
41
43
50
12
1
8
74°
73°
72°
90°
86°
82°

Figure 5.2.7-1: Surface currents in Western Lancaster Sound as presented by (a) Bailey (1957) and (b) Collin (1962).

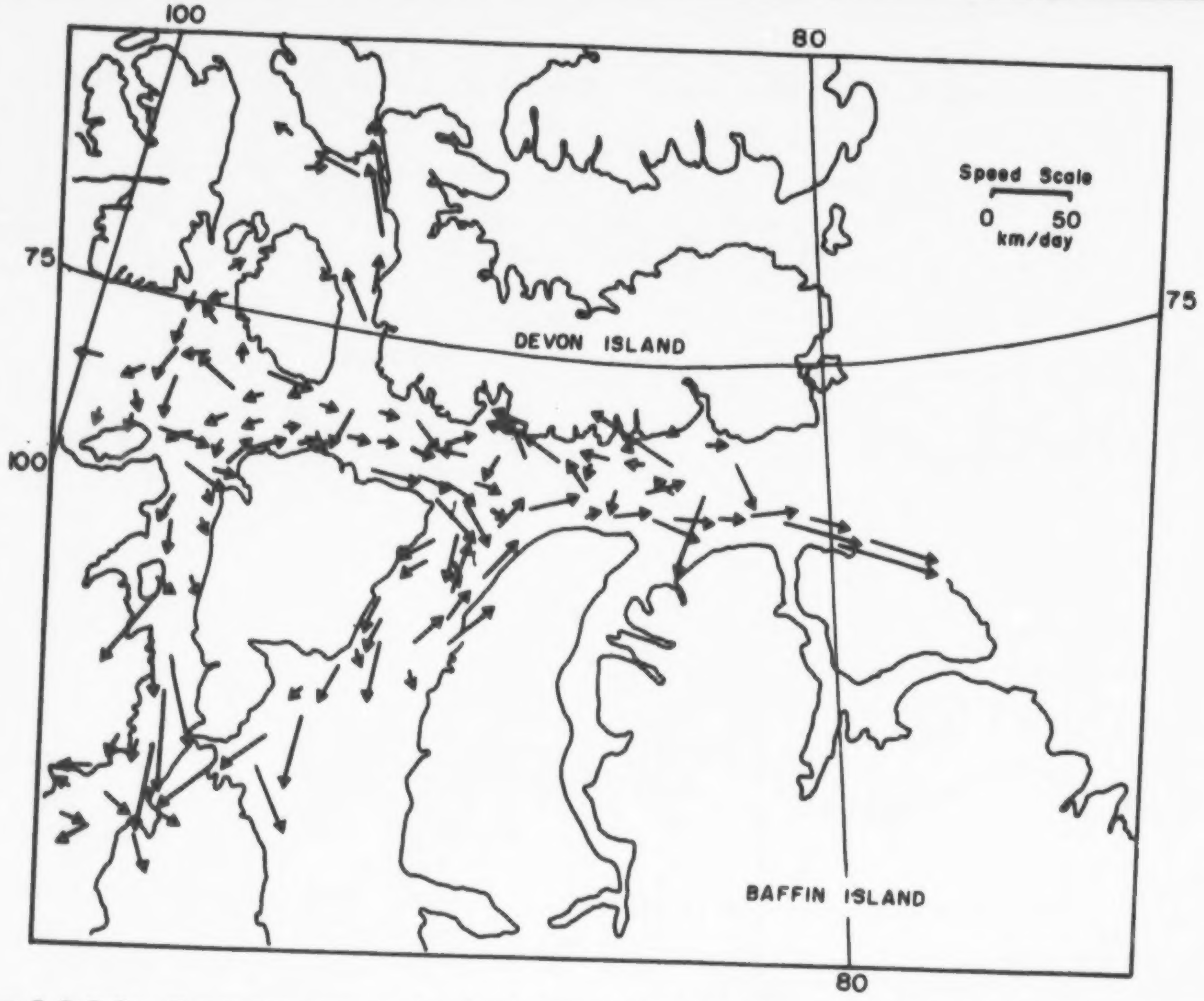

100
80
75
75
100
80
Speed Scale
0 50
km/day
DEVON ISLAND
BAFFIN ISLAND

Figure 5.2.7-2: The vector averaged velocities of all 1977 measurements in eastern Parry Channel. The vector averaging is applied over rectangles with dimensions of 0.2 degrees latitude and 0.8 degrees longtitude (Fissel and Marko, 1978).

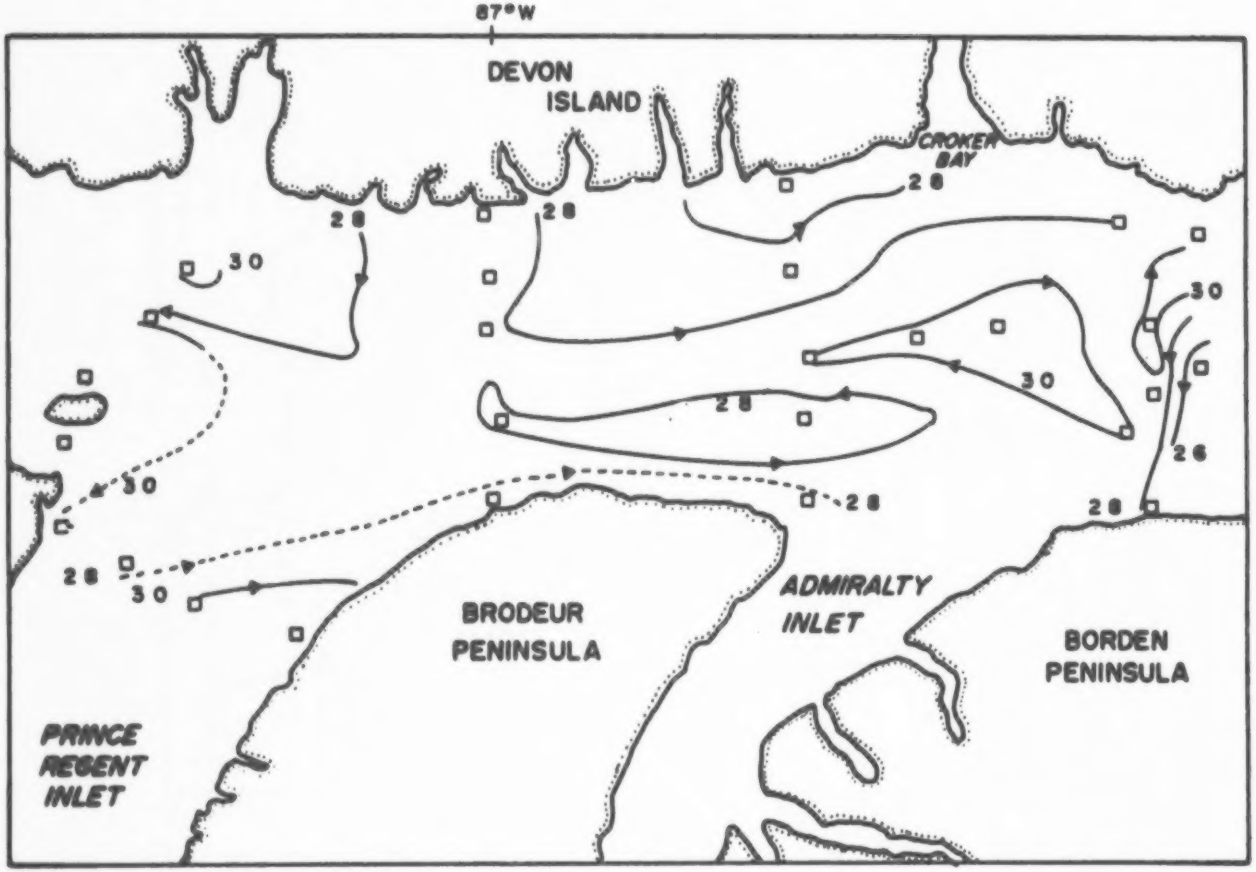

87°W
DEVON ISLAND
CROKER BAY
28
28
28
30
30
28
30
26
28
28
30
28
30
ADMIRALTY INLET
BRODEUR PENINSULA
BORDEN PENINSULA
PRINCE REGENT INLET

Figure 5.2.7-3: Dynamic topography of the surface relative to 175 dbar for the period August 24 to September 6, 1979. Contour interval is 2 dynamic cm.

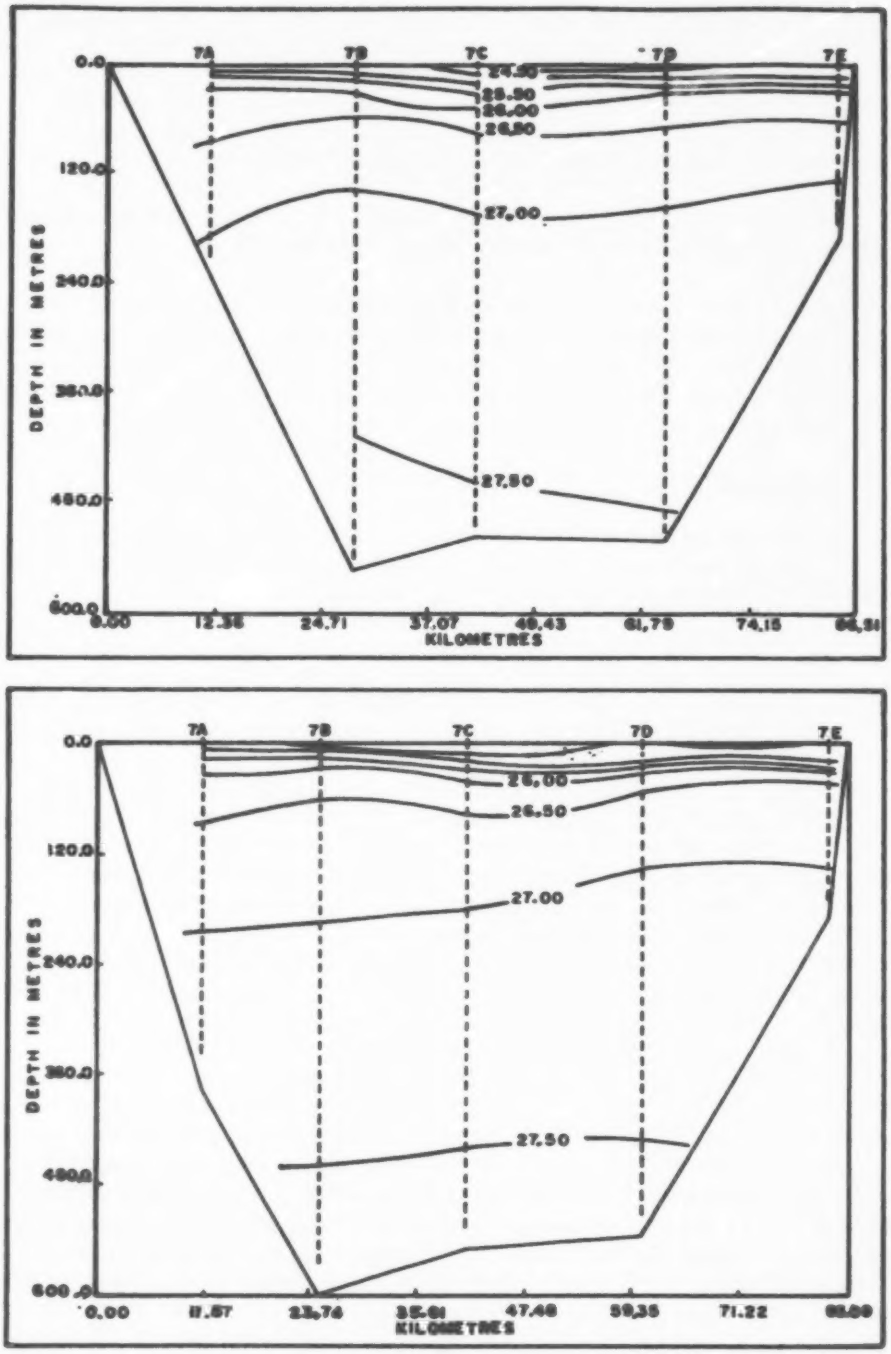


Figure 5.2.7-4&5: σ_t 7-4 section, line 7, August 24, 1979 and 7-5: σ_t section, line 7, Sept. 13, 1979.

> "...provid[ing] good evidence for eastward and westward current flow near the southern and northern edges respectively of Lancaster Sound ... [with] frequent diversions of these flows ... associated with current gyres ... in mid-Sound. ...The scales of the observed gyral circulations ranged from 30 to 60 km..."

In all three figures (5.2.7-1(a), -1(b), and 5.2.7-2) an intrusive flow into Prince Regent Inlet is also shown.

Previous data sets therefore indicate a complex circulation pattern with both eastward and westward flows occupying, along with transient gyres or eddies. The 1979 data, while not nearly as detailed as that collected further to the east, may help to add some more information to this rather confusing picture.

Surface Circulation - 1979 Data

Data available from 1979 consists of the tracks of 14 drifting buoys, released between August 23 and September 14, 1979, and CTD casts taken at lines 7 to 10, between August 24 and September 6, 1979. Line 7 was re-occupied September 13, 1979. Figure 5.2.7-3 shows the dynamic topography of the surface relative to 175 metres for the stations occupied between August 24 and September 6, 1979. No continuous eastward flow is apparent in the main channel, with the exception of a current issuing from Prince Regent Inlet which is visible along the south side as far as Admiralty Inlet. Eastward flow is apparent along the north side, east of 87°W longitude; with a band of westward movement separating it from the flow on the south side. West of 87° west, the flow on the north side is to the west, with a band of southward flow separating it from the eastward current. The intrusive flow into Prince Regent Inlet, previously observed by Collin (1962) and Fissel and Marko (1978) is also evident. Figures 5.2.7-4 and 5.2.7-5 show sections taken across the Sound at line 7 (at longitude 84°40' west) on August 24 and September 13, 1979 respectively. The August 24 section forms part of the dynamic topography shown in Figure 5.2.7-3, and shows the eastward flow in the south side (between stations 7A and 7B), the opposing flow in the centre of the channel (between stations 7B and 7C), and the easterly current on the north side (stations 7C to 7E). Figure 5.2.7-5 shows the same section, occupied on September 13. The band of westward flow has weakened considerably, leaving a general easterly trend over the whole width of the Sound. Further estimates of changes in the circulation in this region during 1979 will have to be made from the tracks of the surface drifters.

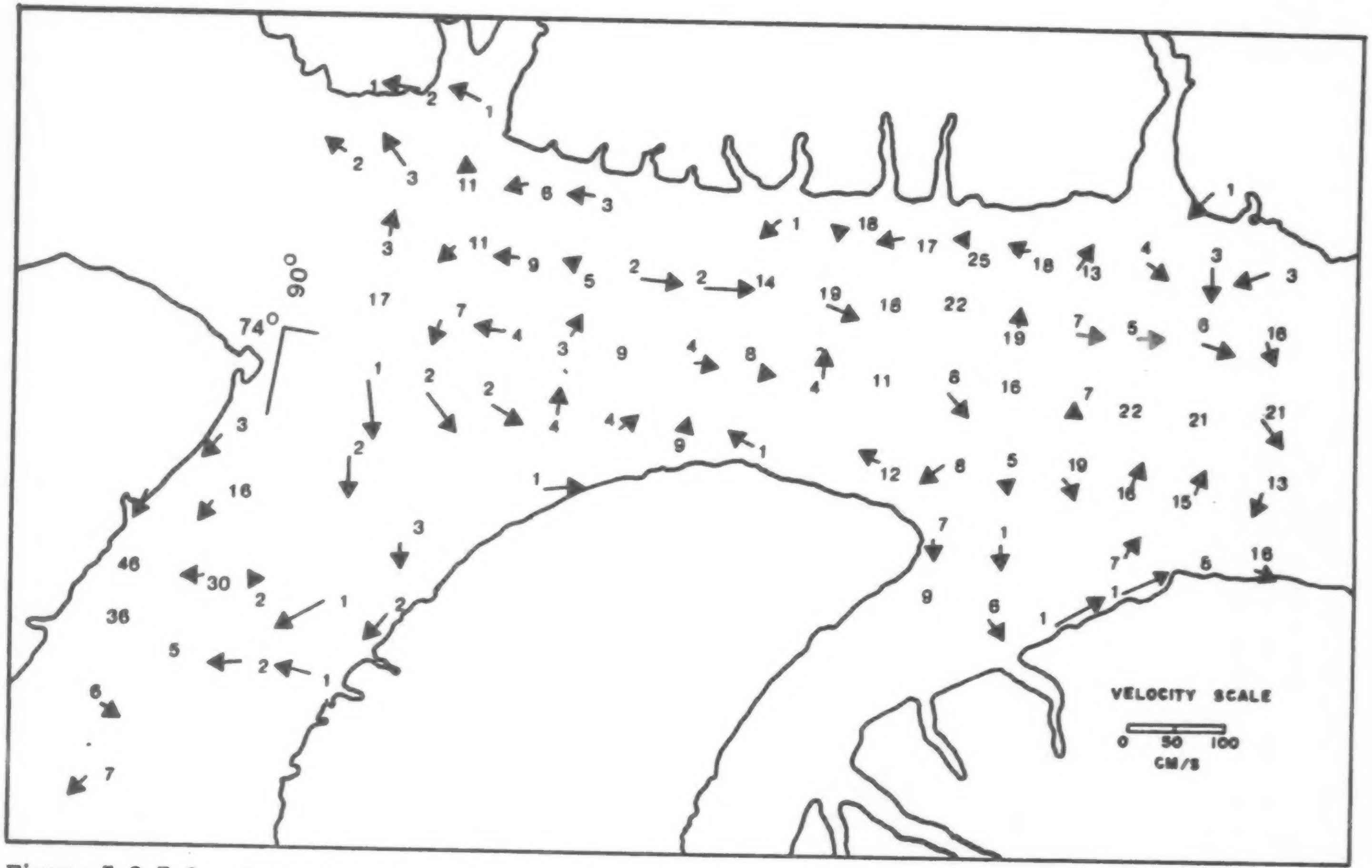

74°
90°
VELOCITY SCALE
0 50 100
CM/S

Figure 5.2.7-6: Composite plot of averaged drifter velocities August 12 - October 29, 1979.

Figure 5.2.7-6 shows the current field derived from the paths of all the 1979 drifters which passed through this part of the Sound. Each arrow represents the vector-averaged velocity of all the drifters which passed through the 0.50° in longitude by 0.167° in latitude grid square, centred on the base of the arrow. The figure covers the period from August 12 to October 29, 1979.

The current field in Figure 5.2.7-6 is very disordered, and does not show any strong, well-developed flows, nor does it show any clear evidence of a net flow in either direction through the Sound. This flow field, however, is by no means synoptic, as it represents data collected over a three-month period. If the flow field is not steady, important features may have been obscured. The figure does demonstrate, however, that there was no steady, localized flow in this part of Lancaster Sound, in contrast to the pattern at the eastern end of the Sound. If any continuous flow from one end of the Sound to the other does exist, then it must shift its position from time to time, so as to be obscured in the average.

Figures 5.2.7-7(a), (b) and (c) show vector-averaged drifter velocities for the periods August 23 to 30, August 31 to September 12, and September 13 to October 29, 1979. The data in Figure 5.2.7-7(a) is sparse; it is inadequate to cover all of the Sound. Thus, while eastward flow at 22 cm/sec is apparent in mid-channel north of the Brodeur Peninsula, it is based on the track of only one drifter (1952), which then turned north and grounded on Devon Island. It is possible that a band of eastward flow existed between the path of drifter 1952 and the Brodeur Peninsula coast, as is suggested in the dynamic topography of Figure 5.2.7-4, but there is insufficient data to state whether or not that was the case.

Westward flow on the north side (west of 88°) at about 15 cm/sec is also present, as was suggested by Figure 5.2.7-3. Figure 5.2.7-7(b), covering the period August 31 to September 12, does show a continuous meandering eastward flow, averaging about 35 cm/sec, which persists until it encounters the complex zone west of the intrusive current. Note that some westward motion occurred off the Brodeur Peninsula, and that the eastward drift occurred in the centre of the chennel. Drifter 1979, released in the channel between Prince Leopold Island and Somerset Island, moved downw the western side of Prince Regent Inlet at an average speed of 30 cm/sec. Figure 5.2.7-7(c) shows the vector-averaged drifter velocities for the period September 13 to October 29, 1979. Eastward flow is confined to the northern half of the channel, separated from the Devon Island coast by a band of westward motion. Speeds in the easterly current ranged from 17 to 40 cm/sec, while those in the narrower westerly band were less than 17 cm/sec. On the south side, there is no clear flow; only a series of loops and eddies.

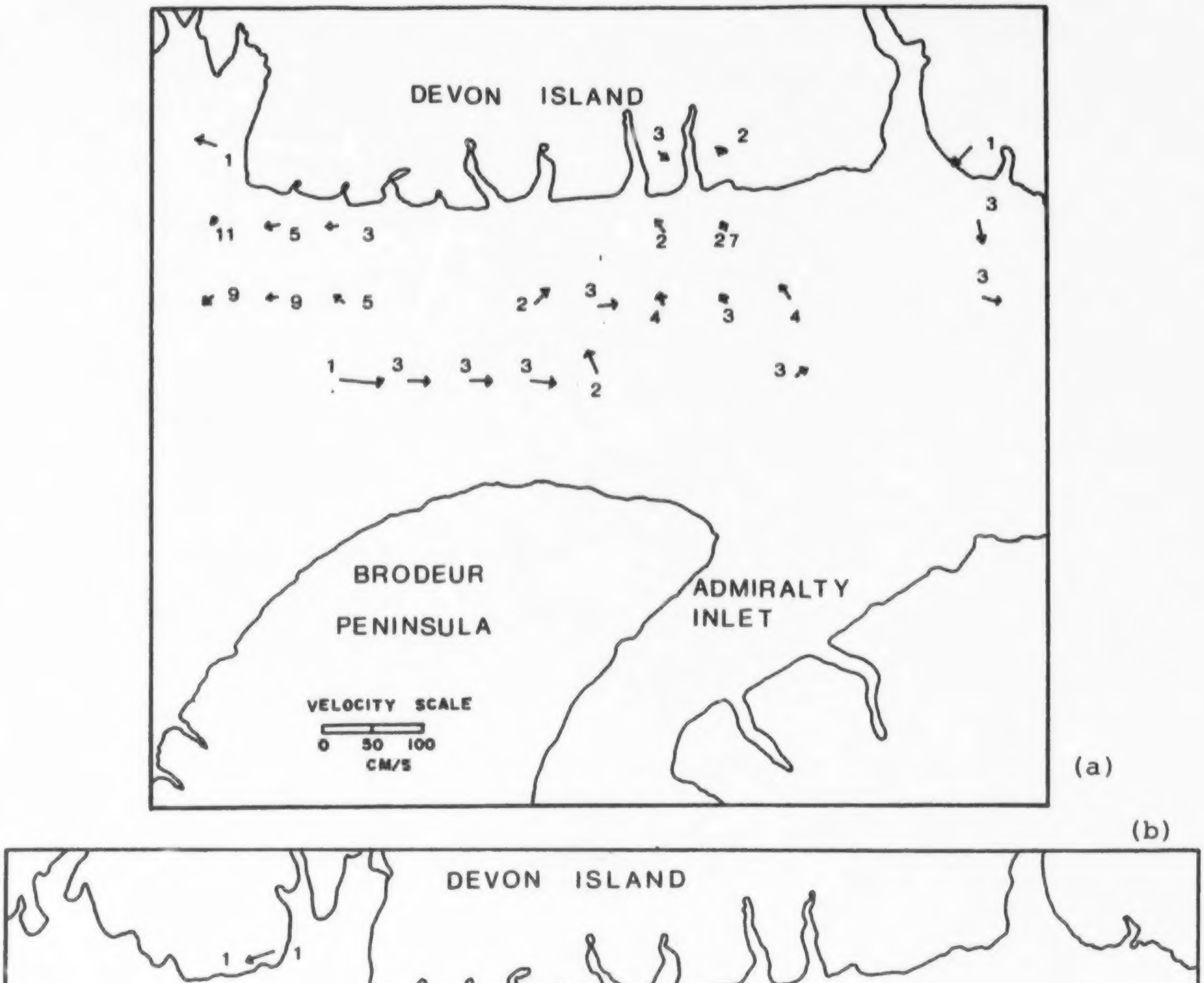

DEVON ISLAND
BRODEUR PENINSULA
ADMIRALTY INLET
VELOCITY SCALE
0 50 100
CM/S
(a)
(b)
DEVON ISLAND
BRODEUR PENINSULA
ADMIRALTY INLET
VELOCITY SCALE
0 50 100
CM/S
74°
90°

Figure 5.2.7-7(a)&(b): Averaged drifter velocities: (a) August 23-30, (b) August 31 to September 12.

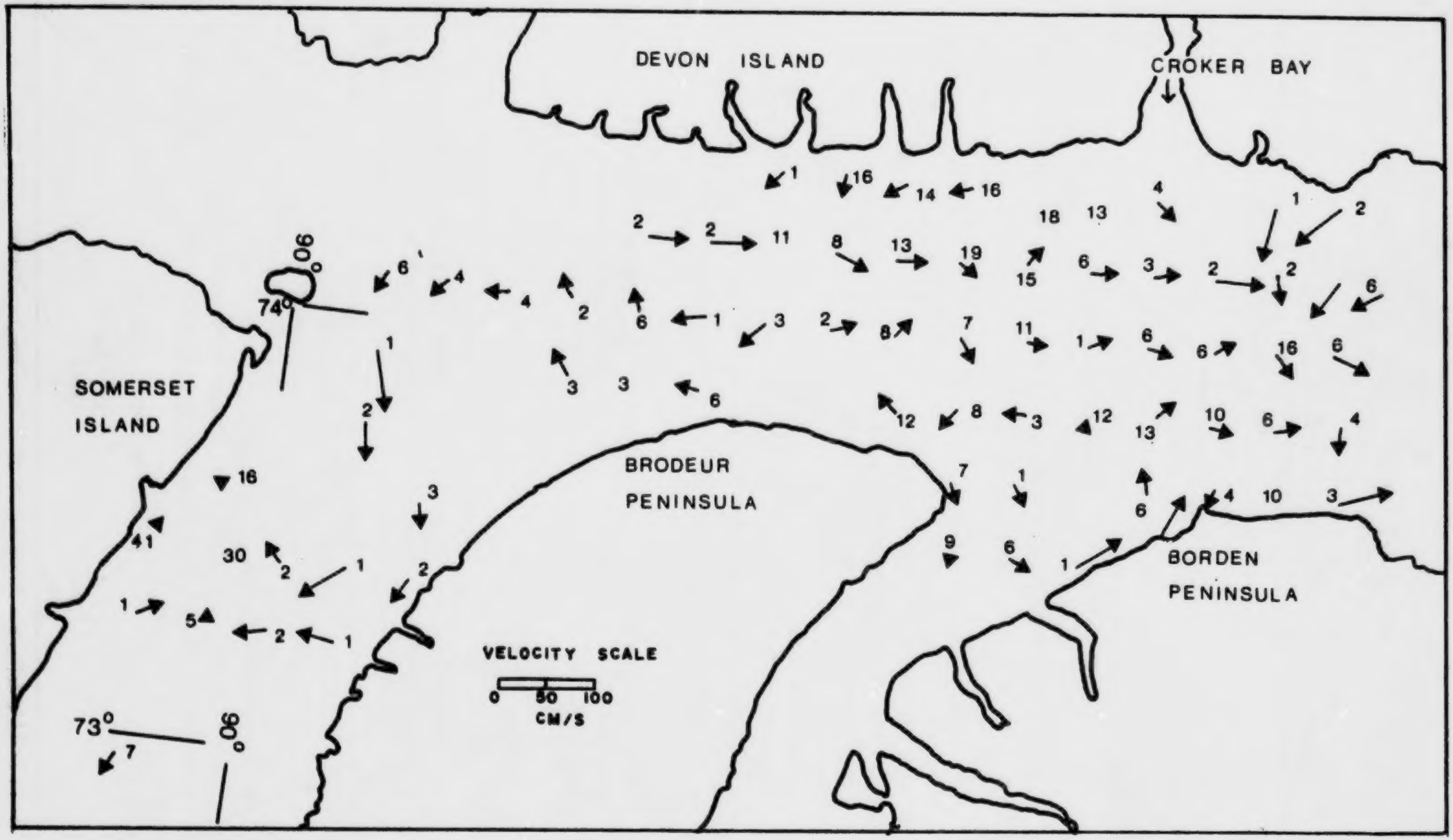

DEVON ISLAND
CROKER BAY
SOMERSET ISLAND
BRODEUR PENINSULA
BORDEN PENINSULA
VELOCITY SCALE
0 50 100
CM/S
90°
74°
73°
90°

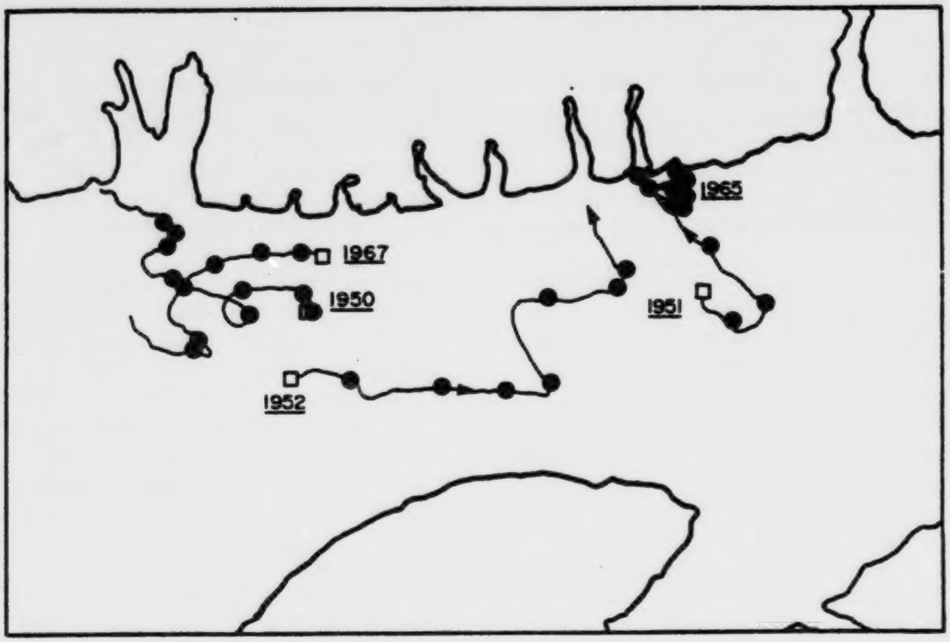
Figure 5.2.7-7(c): Averaged drifter velocities: (c) September 13 to October 29, 1979.

The overall pattern of flow derived from the average drifter velocity fields in Figs. 5.2.7-7(a-c) and from the DTD data in Fig. 5.2.7-3 shows no persistent pattern of surface flow. Any direction of motion is possible at a given point in the channel, with the only apparent exceptions being the entrances to the large inlets on the south side where intrusive patterns are common.

Since the circulation in this section of Lancaster Sound is of such a disordered nature, the question arises whether there is nay net surface drift, i.e. whether or not a given parcel of water is likely to exhibit any long-term motion, and if so, in what direction. Consider the 12 drifters released in 1979. Their tracks are shown in Figures 5.2.7-8(a-c), which show the tracks for all the drifters released in this area, split into the same three time periods as Figure 5.2.7-7(a-c). Six of the drifters were released between 84° and 86° west. Three of these exited to the east (i.e., passed over the line between Croker Bay and Cape Charles Yorke into the area of the intrusive current) and did not return. Of the remaining three, one travelled wastward beyond 86° west, where it probably encountered ice and subsequently exited to the east; the second left to the east after executing several slow circles (it also was surrounded by ice at that time), and the third showed no net east-west motion, and finally ran aground on the Brodeur Peninsula.

Both drifters released on the north side of the Sound, west of 88° W, travelled steadily westward, and remained on the north side of the Sound while doing so (Fig. 5.2.7-8(a & b)), while one released at the same longitude, but in the centre of the channel, travelled to the east before turning north and running aground on the Devon Island coast. Drifter 1955 was released on the south side of the channel at Cape York (87° West longitude), and travelled east as far as 82° W before reversing its motion and returning on the south side to 84° W longitude. The two drifters released near Prince Leopold Island both went down into Prince Regent Inlet, although the drifter released to the east of the island traversed the mouth of the inlet twice before entering it. There was up to 3/10 ice cover at that time in the mouth of the inlet, which may hve had some effect on its motion.

There does seem to be a net eastward drift, i.e., most drifters which did not run aground exited to the east. Six of the total of twelve drifters released exited to the east (including 5 of the 6 released between 84° and 86° west). The only sustained westerly motion occurred on the north side, west of 88°.


1965
1967
1950
1951
1952

(a)

(b)

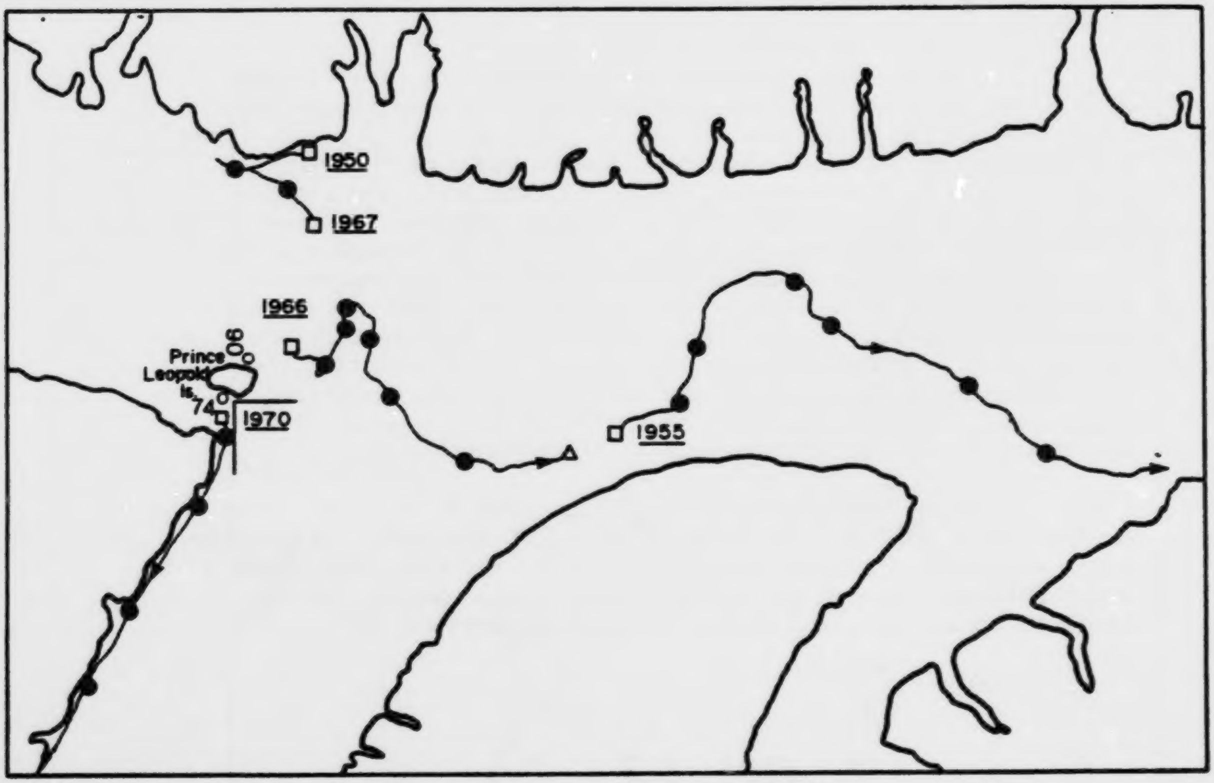

1950
1967
1966
90
Prince
Leopold
Is.
74
1970
1955

Figure 5.2.7-8(a)&(b): Drifter track plots for periods (a) August 23-30, and (b) August 31 to September 12.

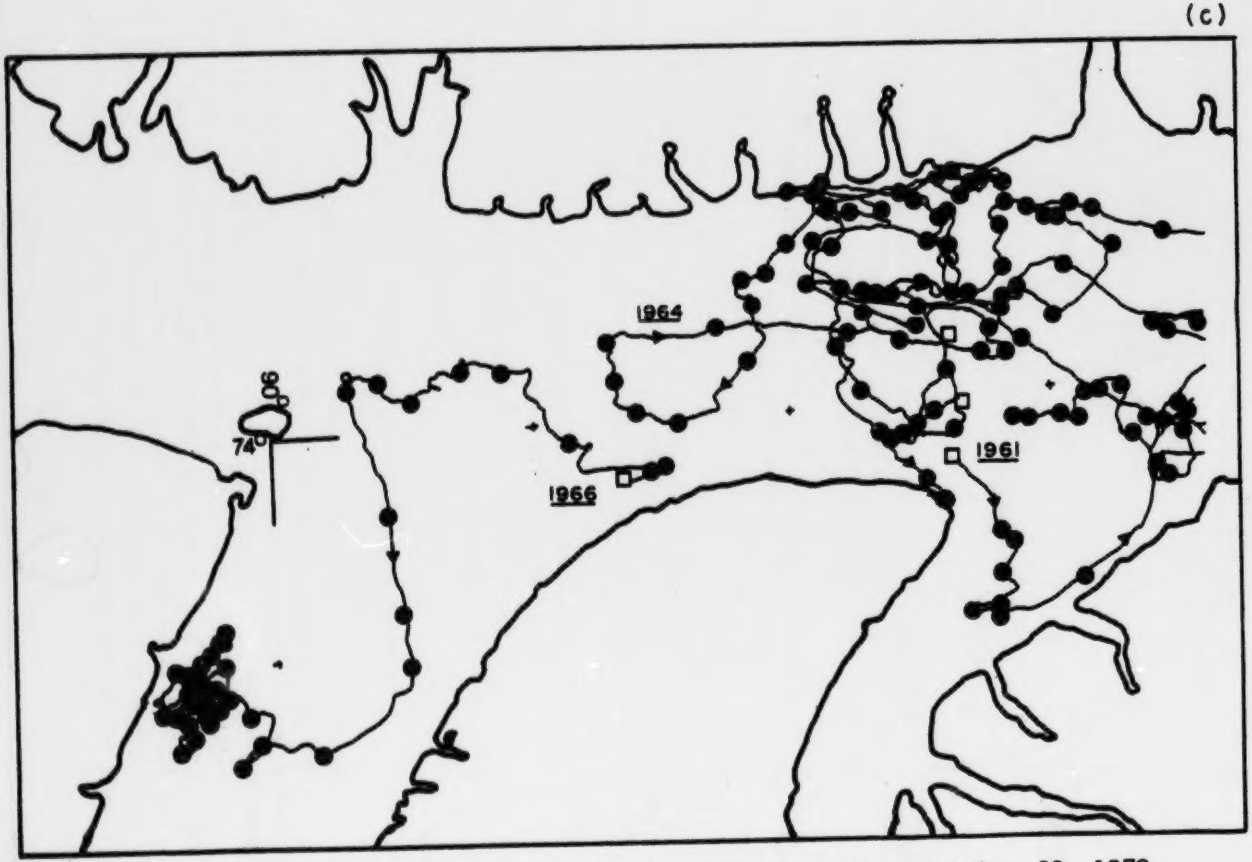

(c)
1964
1961
1966
90°
74°

Figure 5.2.7-8(c): Drifter track plot for (c) September 13 to October 29, 1979.

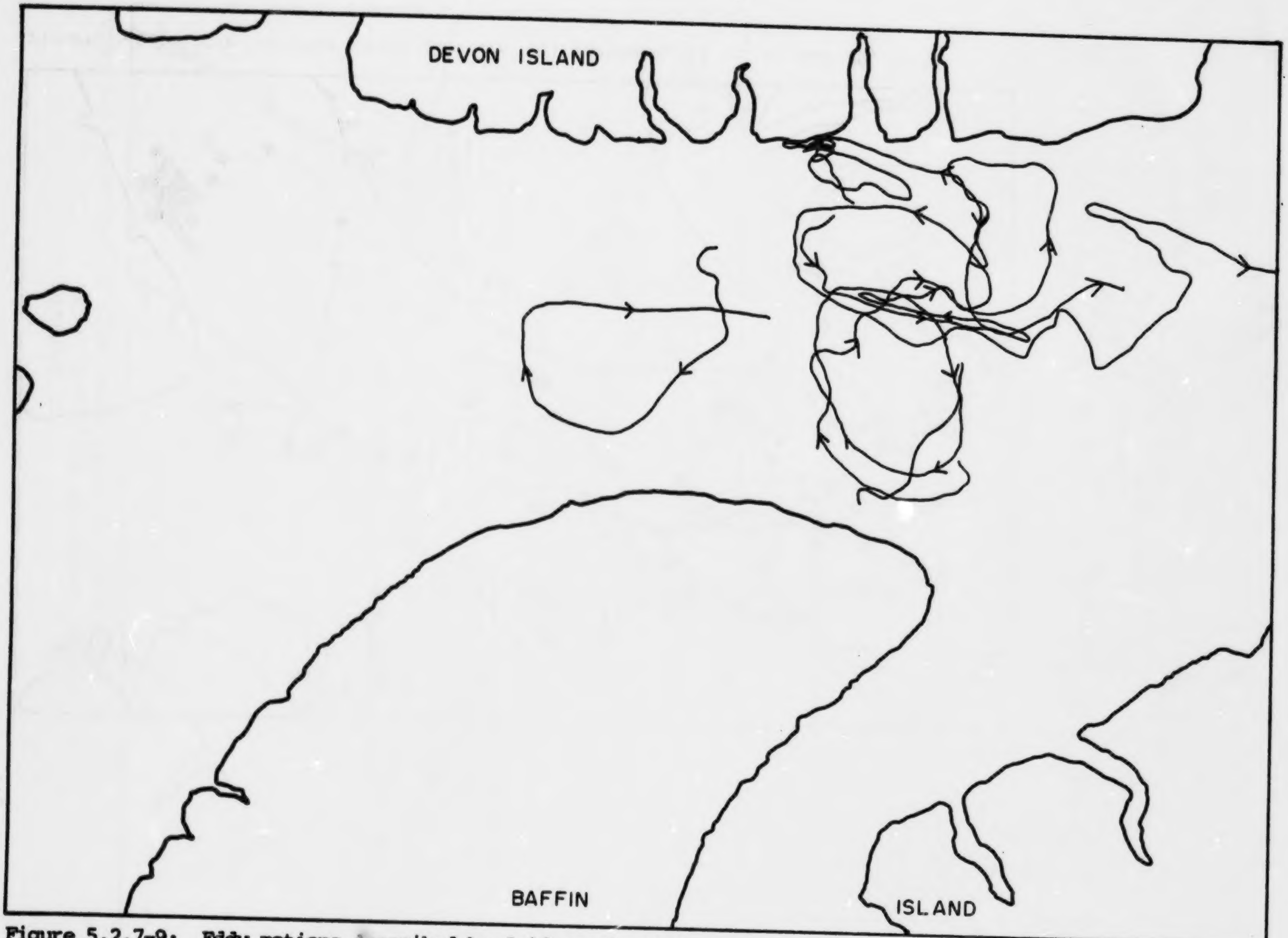

DEVON ISLAND
BAFFIN
ISLAND

Figure 5.2.7-9: Eddy motions described by drifters in 1979.

Several of the drifters executed large-scale loops north of the Brodeur Peninsula. Table 5.2.7-1 shows the characteristics of these eddies, whose locations are shown in Figure 5.2.7-9.

Table 5.2.7-1

Eddy Parameters - Western Lancaster Sound

Average Diameter (km)	Sense of Rotation	Period (Days)
26	Cyclonic	10
25	Cyclonic	5
30	Anticyclonic	5
25	Cyclonic	6
30	Anticyclonic	4
20	Cyclonic	8

The average diameter of all the eddies which were described is 26 ± 4 km. They occurred with both cyclonic and anticyclonic senses. The average period for all cases is 6 ± 2 days.

The surface circulation in 1979 was more disordered than that described by Fissel and Marko (1978) in 1977 (see Section 5.2.7). There was a significant difference in ice coverage for the two years (1977 being a much lighter ice year), which may account for some differences, as the 1979 ice may have interfered with the drogued drifters quite significantly (two of the original 14 were destroyed almost immediately after deployment). There was evidence for a net eastward flow, but it was not confined to the south side of the channel as suggested by the 1977 observations. Westware flows were observed on the north side, but they were never continuous or sustained east of 88° west. Eddy motions occurred north of Brodeur Peninsula, but were on a slightly smaller scale than those observed in 1977.

5.2.8 Navy Board Inlet - Eclipse Sound - Pond Inlet

These three water bodies form a relatively sheltered passage between Bylot Island and Baffin Island. Depths in the centre of Navy Board Inlet are about 300 - 400 m (see Figure 5.2.8-1 for bathymetry data) with sills of about 130 m depth separating Navy Board Inlet from Lancaster Sound to the north, and from Eclipse Sound to the south. Depths in the central portion of Eclipse Sound are about 700 - 800 m and increase to the east reaching depths in excess of 1000 m in eastern Pond Inlet. Further to the east, Pond Inlet becomes shallower with depths of 600 m at the mouth of the Inlet.

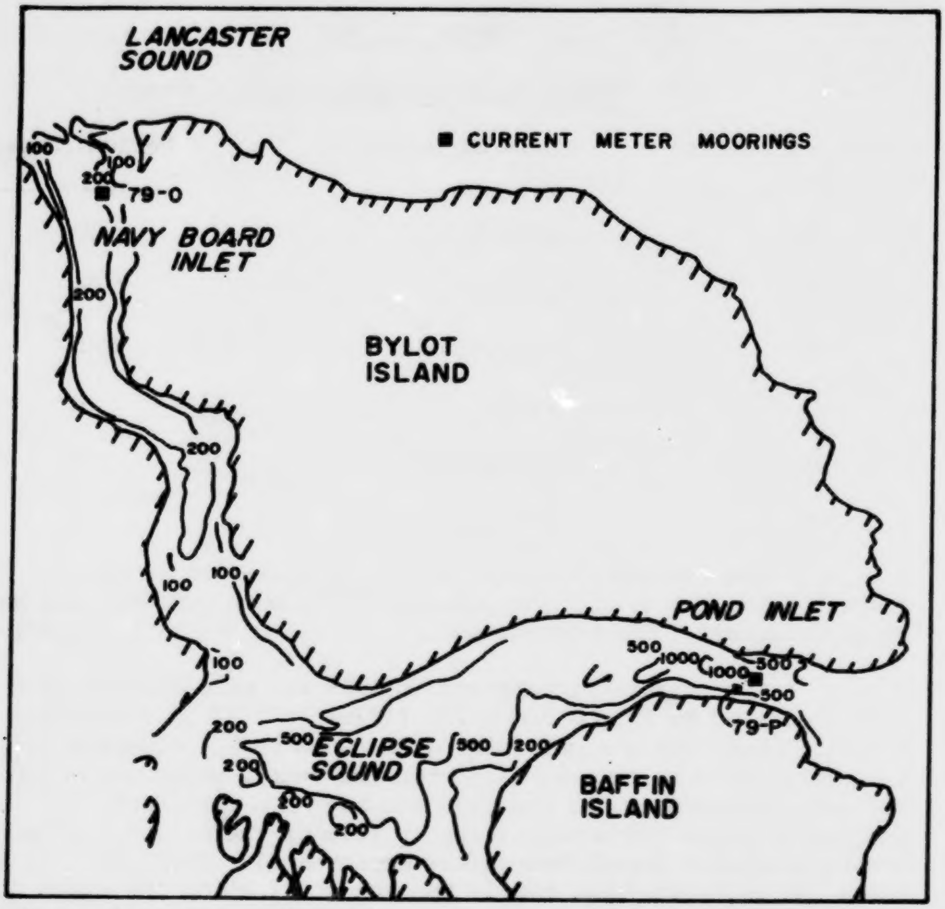
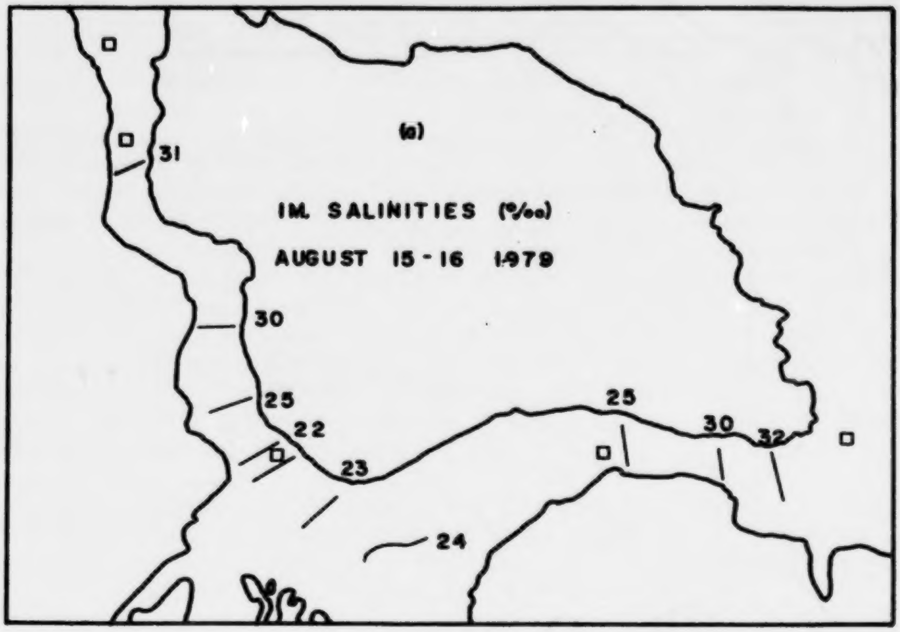

LANCASTER SOUND
■ CURRENT METER MOORINGS
100
200
79-0
NAVY BOARD INLET
BYLOT ISLAND
POND INLET
500
1000
79-P
ECLIPSE SOUND
BAFFIN ISLAND

Figure 5.2.8-1: Bathymetry of Navy Board Inlet, Eclipse Sound and Pond Inlet from Canadian Hydrographic Service Chart 7220. Depths are in meters.


(a)
IM. SALINITIES (‰)
AUGUST 15-16 1979
31
30
25
22
23
24
25
30
32

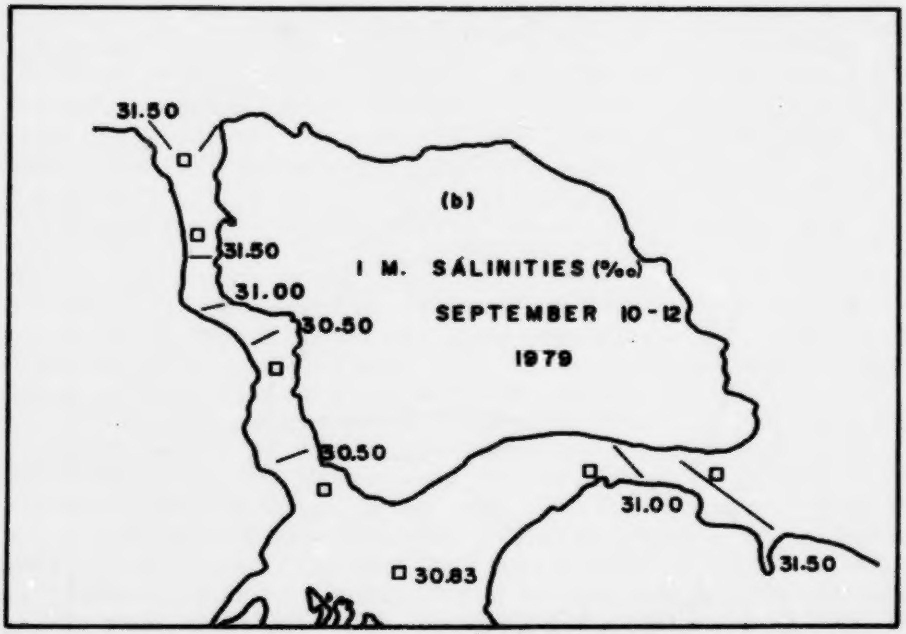
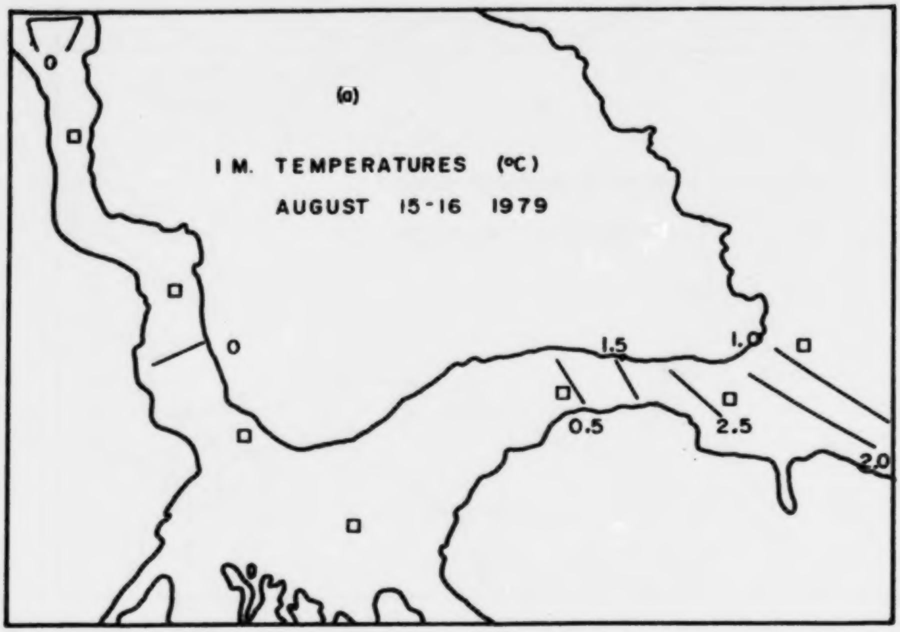

31.50
(b)
31.50
I M. SALINITIES (‰)
31.00
SEPTEMBER 10-12
30.50
1979
30.50
31.00
31.50
30.83

Figure 5.2.8-2: Salinities at 1 m depth for (a) August 15-16, 1979 and (b) September 10-12, 1979.


(a)
1 M. TEMPERATURES (°C)
AUGUST 15-16 1979
0
0
1.5
1.0
0.5
2.5
2.0

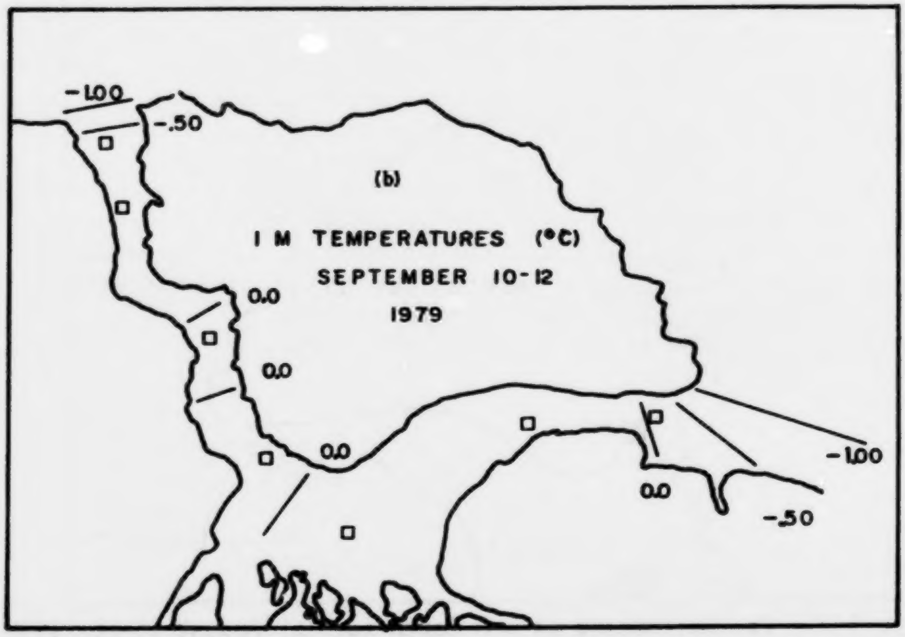

(b)
1 M TEMPERATURES (°C)
SEPTEMBER 10-12
1979
-1.00
-.50
0.0
0.0
0.0
0.0
-1.00
-.50

Figure 5.2.8-3: Temperatures at 1 m depth for (a) August 15-16, 1979 and (b) September 10-12, 1979.

The area to the south of Eclipse Sound is made up of many finger-like inlets and sounds. It is expected that this area will contribute much meltwater and runoff during summer. The surface salinities measured in August and September 1979 support this. In August, surface salinities in Eclipse Sound were reduced to 24 ... by runoff and ice melt (see Figure 5.2.8-2(a)), as compared to simultaneous values of 32 to 33 o/oo in Baffin Bay. By mid-September, surface salinities in Eclipse Sound had increased to about 31 o/oo (Figure 5.2.8-2(b)), likely due to a reduction in the ice-melt and land runoff. Surface temperature gradients were also observed: in August low surface temperatures (0°C) were measured in Eclipse Sound and Navy Board Inlet apparently due to the ice-melt (Figure 5.2.8-3 (a) and (b)), with much warmer temperatures in Pond Inlet (2.5°C). By September, the temperature gradients were reduced with generally warmer temperatures in Navy Board Inlet, Eclipse Sound and Pond Inlet as compared to the adjacent waters of Baffin Bay and Lancaster Sound.

Barber (1977) summarized previous oceanographic data for Eclipse Sound. The best information on currents in this area is provided by the summer 1979 results. The following sections will describe the circulation based on those results.

Drogued Drifter Results

On the basis of the 1978 and 1979 drifter data, there does not appear to be a substantial near-surface flow from eastern Lancaster Sound into Navy Board Inlet. The two major currents in eastern Lancaster Sound, the intrusive current from Baffin Bay (section 5.2.3) and the easterly flow from western Lancaster Sound (section 5.2.7), both carried drifters near the entrance of Navy Board Inlet. In 1978, a total of 7 drifters passed within 20 km of the entrance while in 1979 some 12 drifters approached the entrance to within this distance. Of these, only two drifters (1953 and 1960), entered the Inlet (Figure 5.2.8-4). Both drifters were deployed off the east coast of Devon Island and followed the intrusive current into eastern Lancaster Sound. At the time, early September 1979, the intrusive current was flowing southwest across the Sound (referred to as mode (2) in section 5.2.3). Drifter 1960 turned eastward after nearing the Borden Peninsula coastline and remained about 5 km from shore before turning into Pond Inlet. Another drifter, 1973, was within a few kilometers of 1960 at this time; however, it moved to the east past the entrance to Navy Board Inlet travelling along the Bylot Island coastline. This indicates that the southerly flow into Navy Board Inlet at this time was restricted either to a narrow local circulation feature, or was highly time dependent. The other drifter which entered Navy Board Inlet also was carried by the intrusive current to the Borden Peninsula coastal region. It, however, turned westward upon approaching the Peninsula and described an anticyclonic loop which

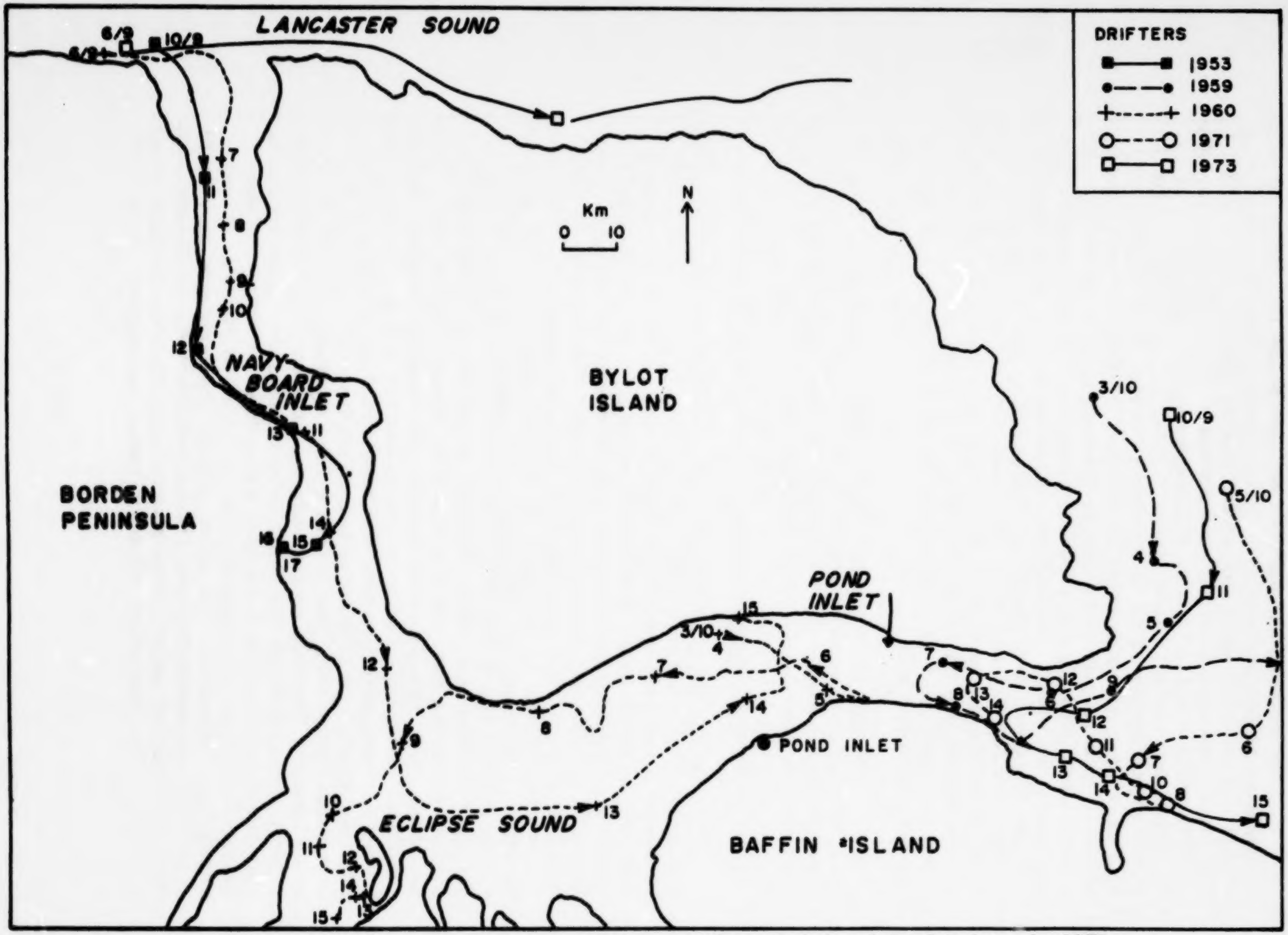

DRIFTERS
1953
1959
1960
1971
1973
LANCASTER SOUND
Km
0 10
N
BYLOT ISLAND
NAVY BOARD INLET
BORDEN PENINSULA
POND INLET
POND INLET
ECLIPSE SOUND
BAFFIN *ISLAND
6/9
6/9
10/9
3/10
10/9
5/10
3/10

Figure 5.2.8-4: Tracks of drifters in Navy Board Inlet, Eclipse Sound and Pond Inlet, in 1979.

which carried it into the mid-Sound area and then south into Navy Board Inlet. Another drifter, number 1958, followed a similar pattern at the same time, but turned left on approaching the entrance to Navy Board Inlet, and travelled eastward along the Bylot Island coast (Figure 5.2.3-10(c)). From these drifter data, it appears that southward flows from Lancaster Sound into Navy Board Inlet are not a major feature of the circulation. The two drifters which did move into Navy Board Inlet both were associated with the southwest mode of the intrusive current; the other mode flows to south-east at mid-Sound, remaining offshore of the entrance to Navy Board Inlet.

Both 1953 and 1960 moved south through Navy Board Inlet at speeds of 20-35 km/day (23-40 cm/sec). 1953 grounded in the southern part of the inlet, whereas 1960 continued into Eclipse Sound (Figure 5.2.8-4), reaching speeds of 30 km/day, prior to running aground on Bylot Island opposite the Pond Inlet settlement on September 15. After beifng towed offshore on October 2, the drifter was carried westward on the north side of the Sound before running aground on Ragged Island. On the basis of this one drifter track, the flows were mainly westerly on the north side of Eclipse Sound and easterly on the south.

Three drifters entered Pond Inlet from the east (see Figure 5.2.8-4). They all entered along the north side and exited along the south in a pattern similar to the intrusive current in eastern Lancaster Sound, with depths of penetration into the inlet of 20, 27 and 36 km. No drifters entered Eclipse Sound through Pond Inlet.

The 1979 drogued drifters indicate a general southerly flow in Navy Board Inlet, variable flows in Eclipse Sound and western Pond Inlet, and an intrusive feature in eastern Pond Inlet.

1979 Current Profiles

Figure 5.2.8-5 is a plot of vector current velocities for stations 15 B-G, September 10-11, 1979, measured by the profiling current meter. Velocities at 4.6 and 38.1 m depths are depicted. The plot suggests generally southerly surface flow in Navy Board Inlet, southerly flow at the one station in Eclipse Sound, and easterly flow in Pond Inlet, implying a net flow from Lancaster Sound to Baffin Bay, through the Navy Board Inlet - Eclipse Sound - Pond Inlet waterway.

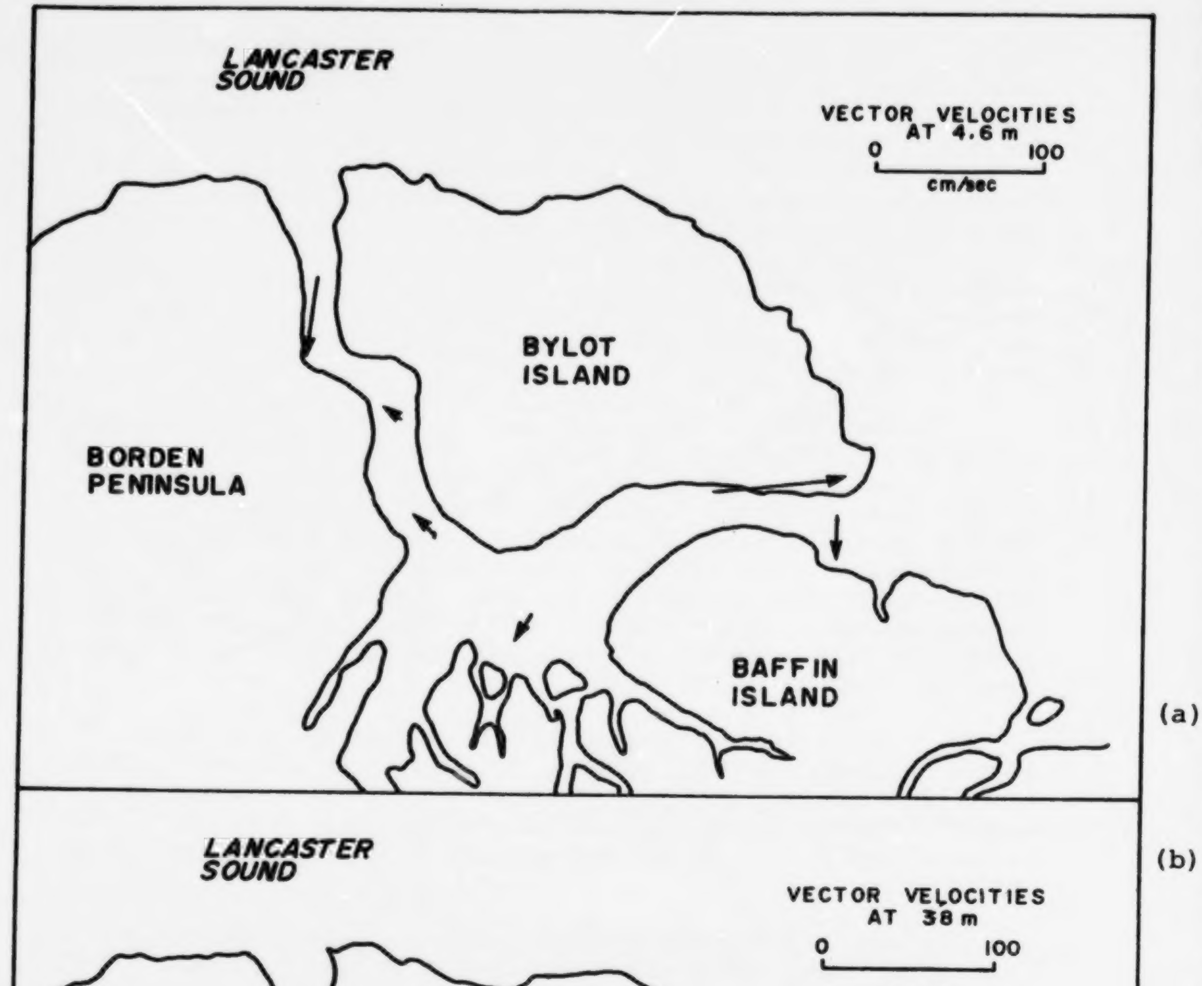

LANCASTER SOUND
VECTOR VELOCITIES AT 4.6 m
0
100
cm/sec
BYLOT ISLAND
BORDEN PENINSULA
BAFFIN ISLAND
(a)
LANCASTER SOUND
(b)
VECTOR VELOCITIES AT 38 m
0
100
cm/sec
BYLOT ISLAND
BORDEN PENINSULA
BAFFIN ISLAND

Figure 5.2.8-5: Profiling current meter results, September 10-12, 1979 at 4.6 m and 38 m depth.

1979 Current Meter Moorings

Two moorings were deployed in this area in the summer of 1979 - one at each of the entrances to Navy Board Inlet and Pond Inlet (see Figure 5.2.8-1 for their locations). Only data from 250 m at mooring O is available. The flow here was mainly southerly during the period August 11 - September 12, but westerly and northerly flows occurred as well. The mean speed was 4.34 cm/sec. The direction histogram was bimodal with the strongest flows at 140° and 310°, reflecting tidal currents.

At mooring P the following records are available:

80 m, August 10 - October 1

250 m, August 10 - September 4

500 m, August 10 - August 15

The currents at 80 m averaged 14 cm/sec; the strongest and most frequent flows were to the east at speeds up to 50 cm/sec; a secondary peak at 330° occurred with maximum speeds of about 30 cm/sec. Tidal flows did not dominate at 80 m; easterly flows at about 20 cm/sec persisted for periods of days. Tidal flow did dominate at 250 and 500 meters with east-west reversals occurring at two cycles per day.

The intrusions into Pond Inlet, as evident in the drifter tracks, occurred over time scales of a few days and therefore are not tidal events.

Summary

During the summer of 1979 the surface circulation in Navy Board Inlet was generally southerly with speeds of 20-30 cm/sec. Data in Eclipse Sound is limited but one drifter indicated westerly flow on the north side and easterly flow on the south, with north - south flows evident at both ends of the sound. In Pond Inlet an intrusive circulation was evident in three drifter tracks, with greatest penetration of 36 km. Inflow was westerly on the north side, with the outflow along the southern side and typical flow speeds of 12-28 cm/s.

Large amounts of freshwater input during summer into Eclipse Sound, due to the melting of sea-ice and land run-off, may drive an estuarine circulation. Given the observed tendency of water movement to the south and then east through the Navy Board Inlet, Eclipse Sound and Pond Inlet waterway, the fresh water outflow from Eclipse Sound appears more likely to exit through Pond Inlet.

A near-surface inflow from eastern Lancaster Sound into Navy Board Inlet, was observed from the tracks of two drogued drifters. However, since many other drifters passed through eastern Lancaster Sound without entering Navy Board Inlet, the southward flow into the Inlet appears to constitute only a small fraction of the total outflow of eastern Lancaster Sound.

5.3 Circulation of Atlantic Water In Lancaster Sound

5.3.1 Introduction

The central portion of the Baffin Bay water column is occupied by Atlantic Ocean water which has moved north through Davis Strait. As was described in Section 3, this water is characterized by temperatures above 0°C, and salinities between 34.2°/oo and 34.5°/oo. Atlantic water occupies the eastern portion of Lancaster Sound as well, where it constitutes all of the water column below the Arctic water layer. Figure 5.3-1 shows a longitudinal section of temperature (below 100 metres) in Lancaster Sound, which shows the warmer Atlantic water occupying the eastern end of the Sound. Note that although some water with a temperature between 0°C to 0.5°C exists west of station 6A, there is a marked decrease in the volume of warm water west of station 6C, and that a considerable horizontal temperature gradient exists between stations 6C and 6D. There is apparently some process other than the shoaling of the bottom to the west which is limiting the penetration of the warmer Atlantic water into the Sound. The position of the horizontal temperature gradient corresponds almost exactly with the position of the intrusive current (see Sectiofn 5.2.3); therefore the intrusive current seems likely to be the cause of the limited penetration of the Atlantic water. If that is the case, the frontal structure associated with the strong cross-Sound flow may be a site of vertical mixing and replenishment of nutrients (Horne, 1978). Let us first, however, examine the circulation of the Atlantic water in the entrance to the Sound.

5.3.2 Circulation Of The Atlantic Water

Direct measurements of currents in the Atlantic water layer are available from the current meter moorings deployed in 1977, 1978 and 1979. Figure 5.3-2 shows the vector average currents at all the 1977 and 1978 current meters in Lancaster Sound. Note that at moorings 5, 7 and 10, the 500 metre flow is westward, into Lancaster Sound, with high steadiness factors (Ramster et. al., 1976) at moorings 7 and 10. At mooring 9, the 750-metre flow is relatively steady and has a significant westward component. The mean temperatures at 500 m at 1978 moorings 5, 7 and 10 were 1.12± .21°C, 1.17± .15°C and 1.52± .14°C. The mean temperature at 750 m at station 9 was 1.01± .07°C.

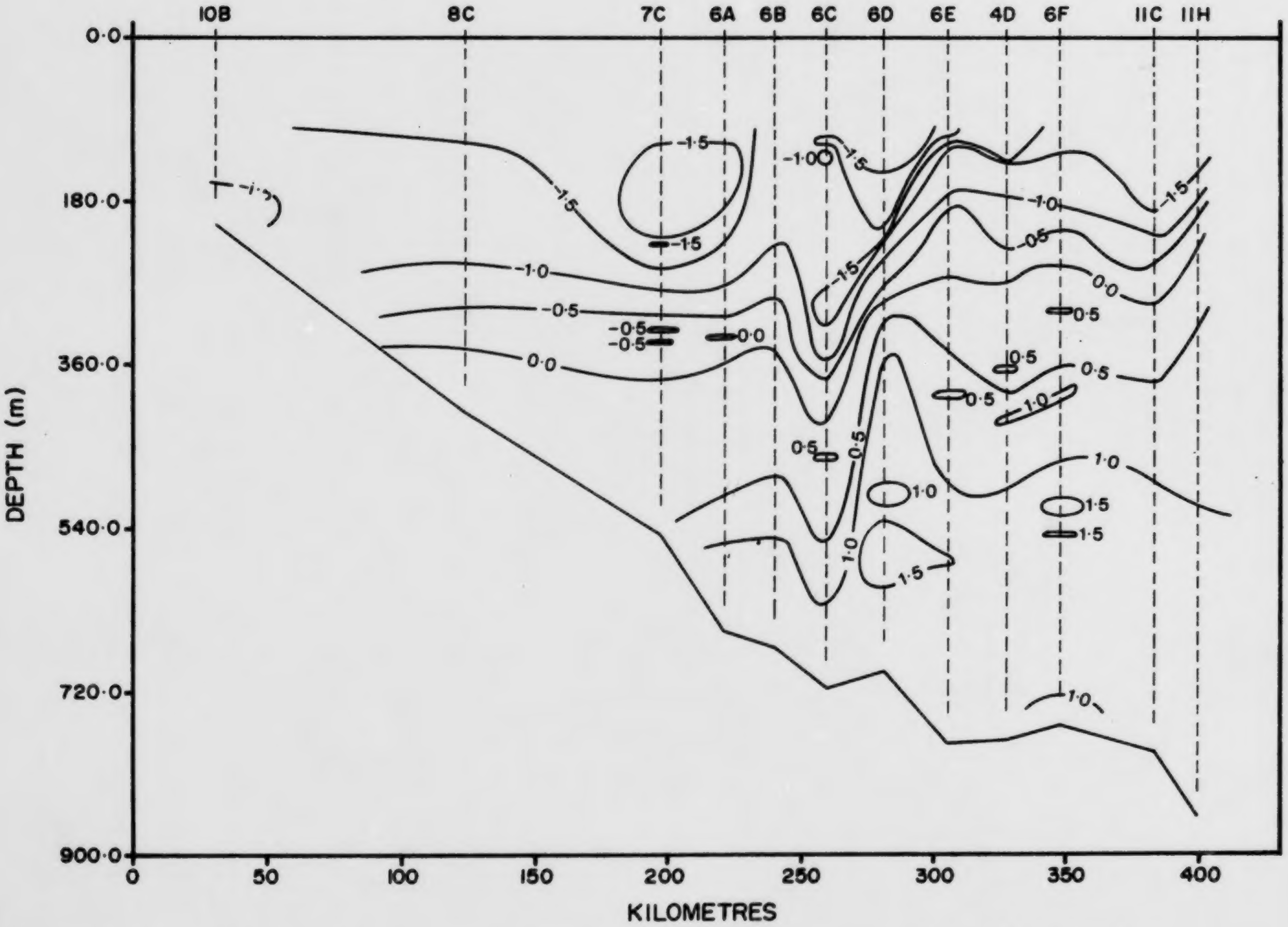


Figure 5.3.1: Longitudinal section of temperatures along the centre of Lancaster Sound below 100 m depth based on August 1979 CTD data.

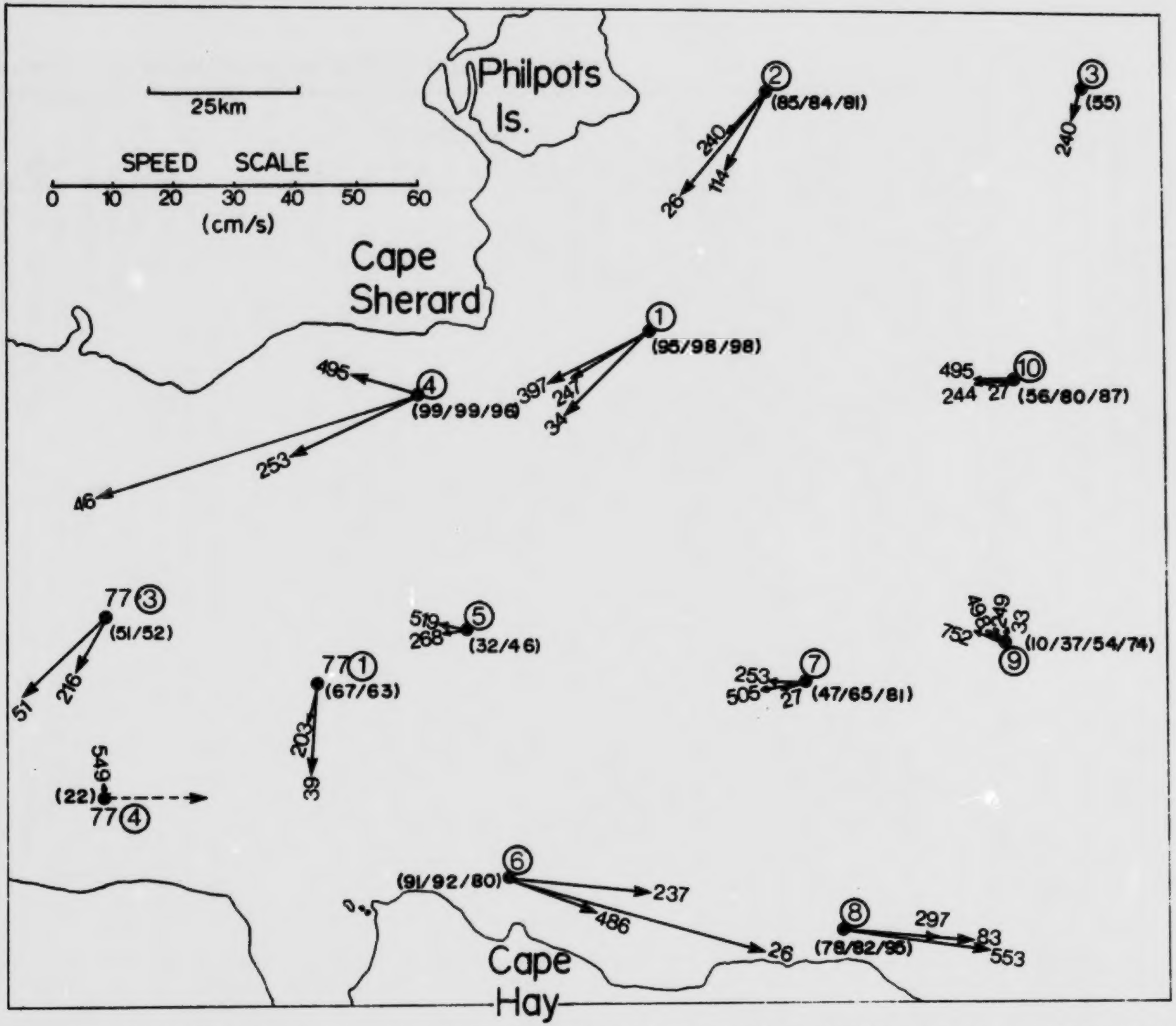

25km
SPEED SCALE
0 10 20 30 40 50 60
(cm/s)
Philpots Is.
Cape Sherard
Cape Hay
② (85/84/91) 240 114 26
③ (55) 240
① (95/98/98) 397 247 34
④ (99/99/96) 495 253 46
⑩ (56/80/87) 495 244 27
77③ (51/52) 216 51
77① (67/63) 203 39
⑤ (32/46) 519 268
⑦ (47/65/81) 253 505 27
⑨ (10/37/54/74) 752 498 249 33
549 (22) 77④
⑥ (91/92/80) 237 486 26
⑧ (78/82/95) 297 83 553

Figure 5.3-2: The vector average current measured at mooring stations in the northern half of the study area. The circled numbers denote the station numbers while the bracketed numbers denote the steadiness factor (see text) in order of increasing depths. Each vector is labelled with the mean depth.

In the intrusive current (e.g., moorings 4, 6 and 8 in 1978), the deep flow is aligned with the intrusive current except, perhaps, at morring 4 and is quite steady (B 80 at all three sites). At mooring 1, the 400 m flow is oriented with the intrusive current but does not always consist of Atlantic water, as the temperature at that current meter varied from 1.83°C to -0.03°C with a mean temperature of 0.58± 0.38°C. Further 1978 information on the western extent of the Atlantic water is available only from the CTD data, all of which are located at or to the east of Cape Warrender. Figure 5.3-3(a-c) shows the distribution of temperature at 500 metres for three periods during the summer of 1978. Fluctuations in the positionof isotherms (e.g., the 1.0° isotherm) of up to 75 km are apparent, but the data do not go far enough west to define fully the extent of the Atlantic water.

The 1977 moorings (77-1, 77-3 and 77-4) provide little information about the deeper currents, as only moorings 77-4 returned speed and direction information at 500 metres. It showed a vector average flow to the north, but with a very low steadiness factor. Temperature data is available for all three moorings at nominal depths of 550 m the mean values are:

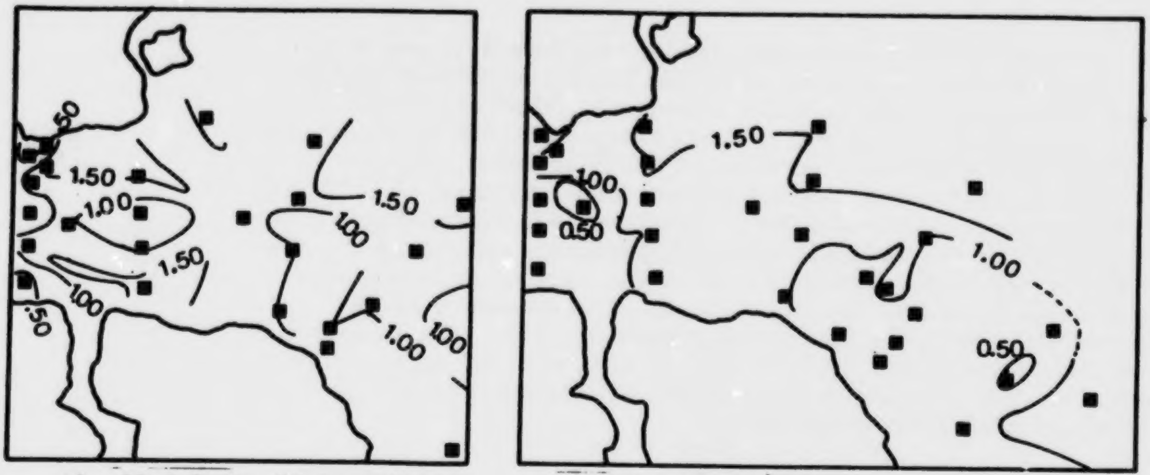
Mooring 77-1: 0.97 ± 0.22°C;
Mooring 77-3: 0.99 ± 0,23°C
Mooring 77-4: 0.93 ± 0.21°C (Fissel and Wilton, 1978).

It seems apparent, then, that Atlantic water existed at 550 metres at all three 1977 moorings, however the lack of current data at that depth prevents deductions about its motion. The 1979 500 metre current data are summarized in Table 5.3-1 below, and the station locations and direction distributions are shown in Figure 5.3-4.

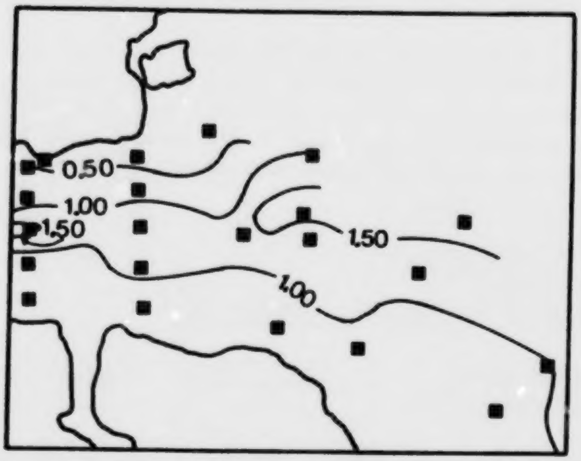
Table 5.3-1

CURRENT DATA AT 500 METRES, SUMMER 1979

Station	Vector Avg. Speed (cm/s)	Vector Avg. Direction (°T)	B	Mean Temp. (°C)	Std. Dev. (°C)	Min. Temp. °C	Max. Temp. °C
G	2.6	39	32	0.17	0.26	-0.12	1.08
H	4.6	139	56	0.56	0.34	-0.21	1.67
I	0.6	37	8	0.46	0.20	-0.05	1.27
J	2.9	84	39	0.45	0.21	-0.02	1.55
K	2.4	334	35	0.55	0.12	0.0	0.91
L	13.2	108	90	0.63	0.28	-0.24	1.48
M	13.9	115	91	0.51	0.16	-0.20	1.23


.50
1.50
1.00
1.50
1.00
.50
1.50
1.00
1.00
1.00
1.50
1.00
0.50
1.00
0.50

a) 23 July to 28 August b) 2 - 16 September


0.50
1.00
1.50
1.50
1.00

c) 17 September to 8 October

Figure 5.3-3: Horizontal distribution of temperature at 500 m, summer 1978.

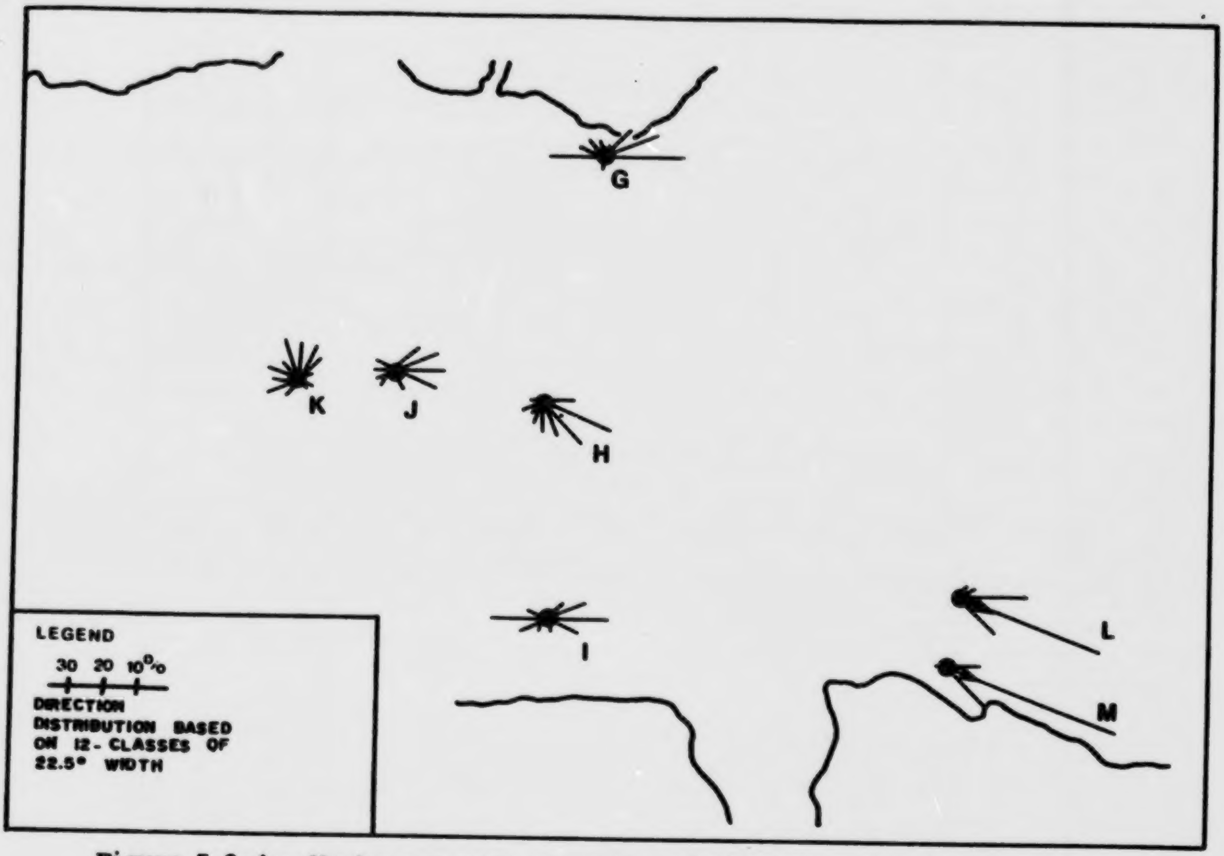

G
K
J
H
I
L
M
LEGEND
30 20 10%
DIRECTION DISTRIBUTION BASED ON 12- CLASSES OF 22.5° WIDTH

Figure 5.3-4: Vector average currents and direction distribution at 500 m, summer 1979.

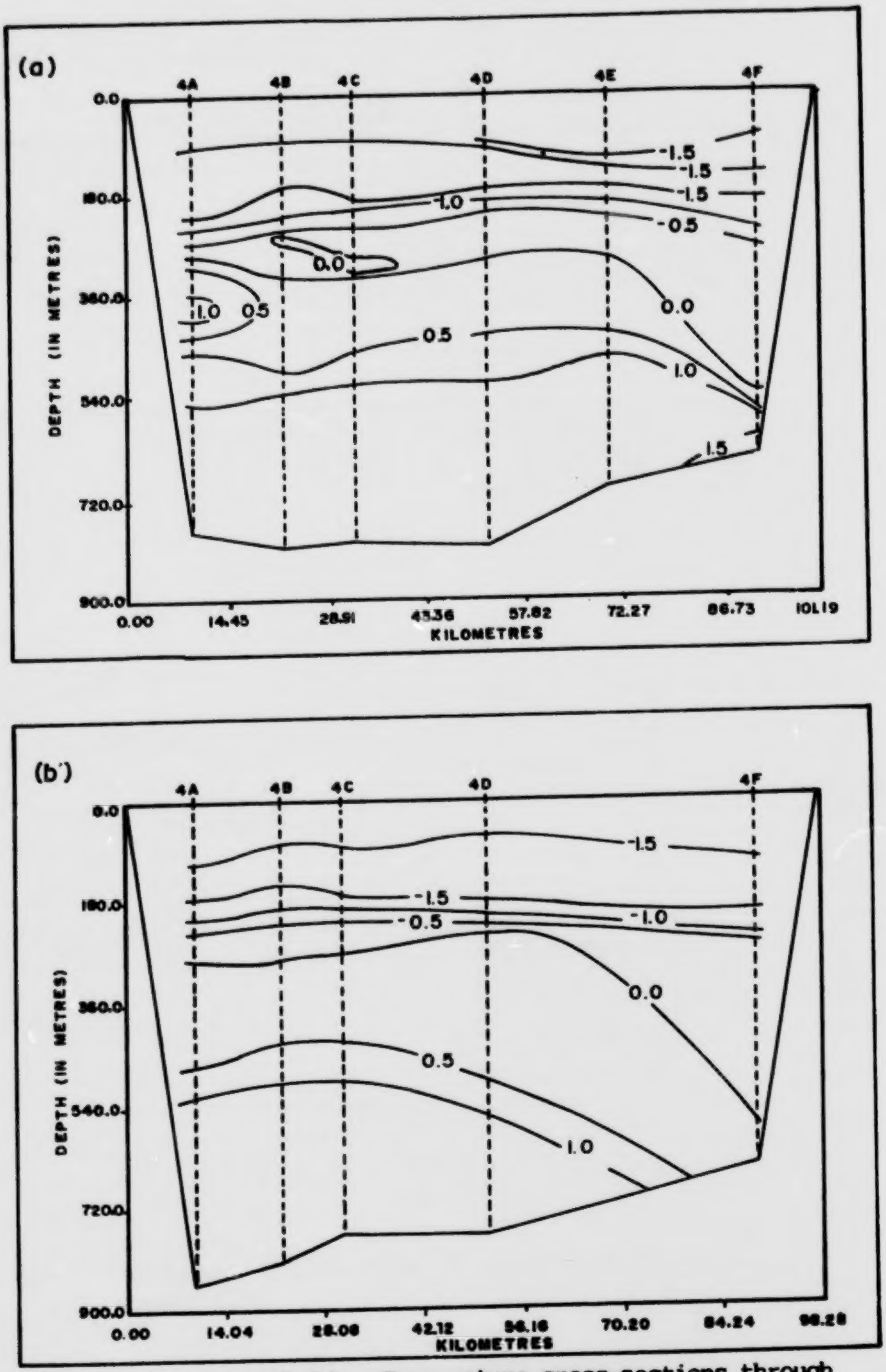


Figure 5.3-5 (a) and (b): Temperature cross-sections through line 4 (a) July 18, 1979 and (b) July 30, 1979.

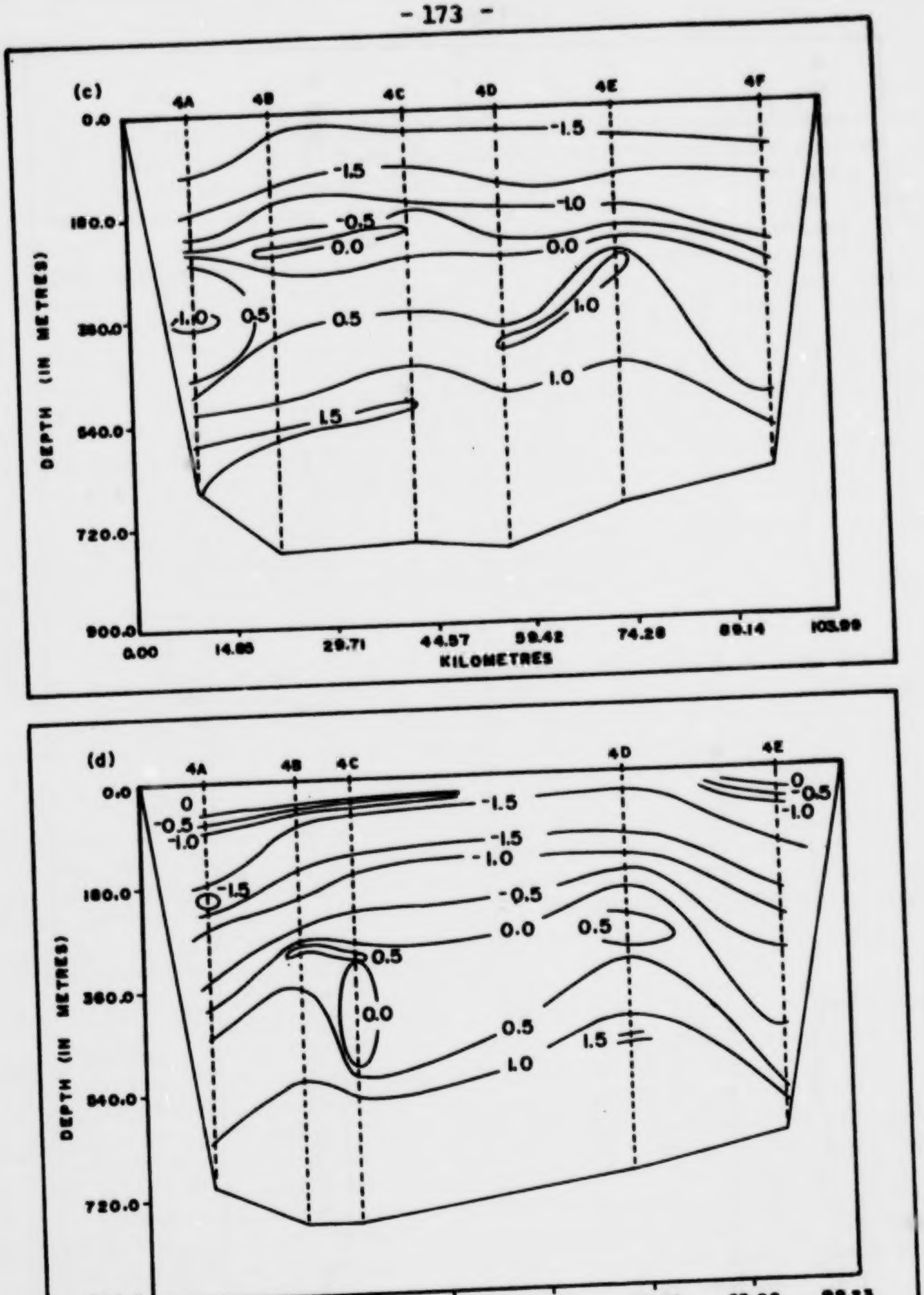
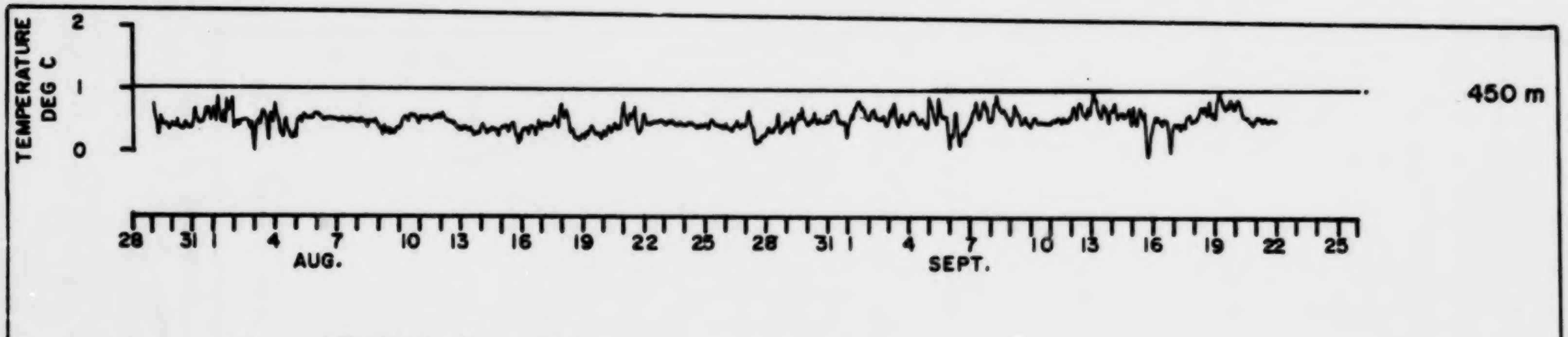
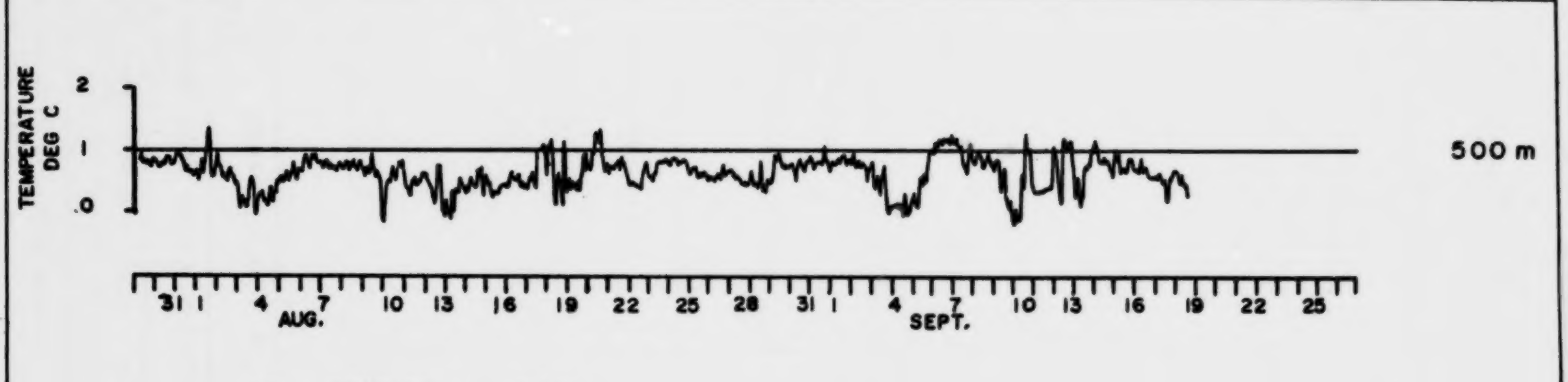


Figure 5.3-5 (c) and (d): Temperature cross-sections through line 4 (c) September 2, 1979 and (d) September 19-21, 1979.



a) STATION M, 450 m



b) STATION L, 500m

Figure 5.3-6: Temperature time series at (a) station M, 450 m depth and (b) station L, 500 m depth, 1979.

Only moorings L and M show significant steadiness factors, (70% or more), which reflect the outflow of the intrusive current along the northern side of Bylot Island. The temperatures from these two moorings indicate that they were not always in the warmer Atlantic waters. Examination of the four available temperature cross-sections at line 4 (Fig. 5.3-5(a-d)) (mooring L is between stations 4A and 4B, while mooring M is between station 4A and the shore), shows that while the mean 500 metre temperatures at each mooring fit well with the sections, the extrema do not. Figure 5.3-6 (a & b) shows the temperature time series at 450 m and 500 m depth. The excursions to colder temperatures ($< 0°C$) are very short with typical durations of one day. They may be due to isolated colder blobs of water advected past the mooring, such as that seen at station 4C in Figure 5.3-5 (d), or to an on or offshore shift in the intrusive current, which could introduce colder water along the shoreline of Bylot Island. Comparison of Figure 5.3-5 (c & d) shows a change such as that. Note that all the sections in Figure 5.3-5 show a greater volume of warm water on the south side of the Sound than on the north side.

The deep currents at the other 1979 current meter stations all show very low steadiness factors, indicating no well-organized pattern of deep flow. Figures 5.3-7 (a-c) show three other occupations of part of the same line of stations shown in Figure 5.3-1. The extent of the Atlantic water does not vary a great deal in each case, although changes in the frontal region between 6C and 6D are apparent. The fluctuations in this region are reflected in the standard deviations of temperature at 500 m for moorings H, J and K (Table 5.3-1) which steadily decrease to the west. Fig. 5.3-8 shows the temperature time series at 500 metres for those moorings, and also illustrates the decrease in variance with increasing distance westward into the Sound.

In summary, there is a significant decrease in the volume of Atlantic water west of the intrusive current, although some does penetrate to the neighbourhood of 86°W. A region of large horizontal temperature gradient at depth coincides with the intrusive current. No steady deep flow was found at current meter stations west of the intrusive current. A steady, strong outflow of Atlantic water was found on the south side of the Sound, as part of the intrusive current. The deep in-flowing part of the intrusive current on the north side, while showing steady flow, did not always consist of Atlantic water. There was, in 1978, a slow, steady inflow of Atlantic water at depth across the east entrance of Lancaster Sound, which appears likely to supply the outflow along Bylot Island. The influx does not extend west of the intrusive current. No attempt has been made to compute whether or not the slow influx of Atlantic water through the entrance of the Sound balances the outflow in the intrusive currents; it is unlikely that the data set is sufficiently complete to justify the attempt.

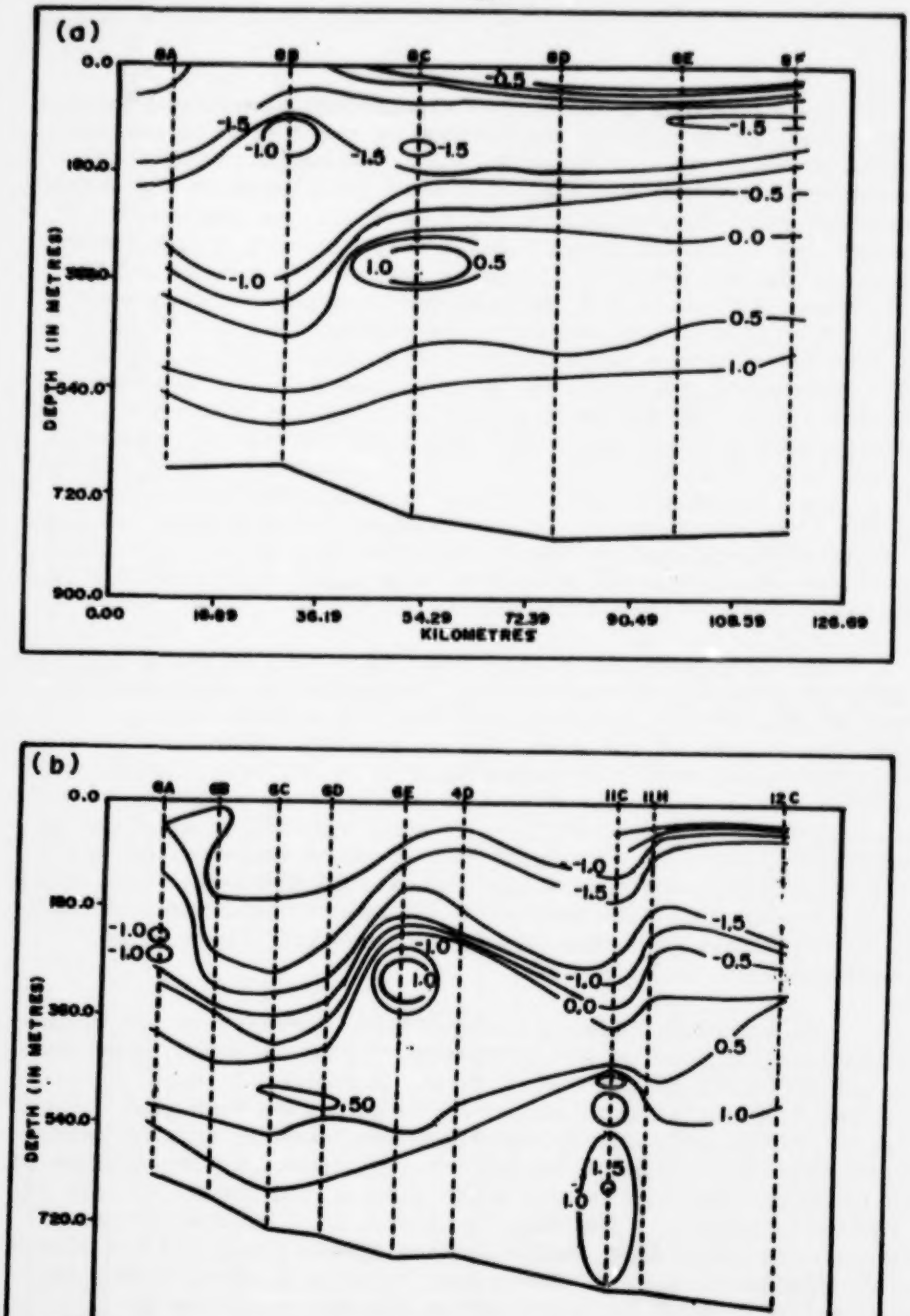


Figure 5.3-7 (a) and (b): Vertical cross-sections of temperature along Lancaster Sound (a) July 19-22, 1979, and (b) July 29 to August 4, 1979.

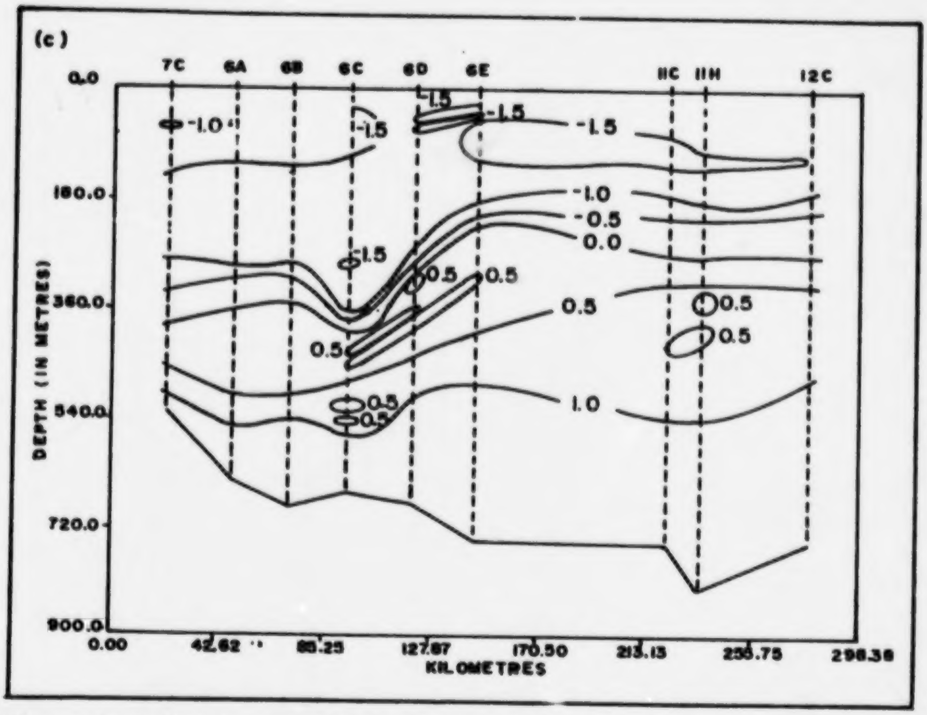
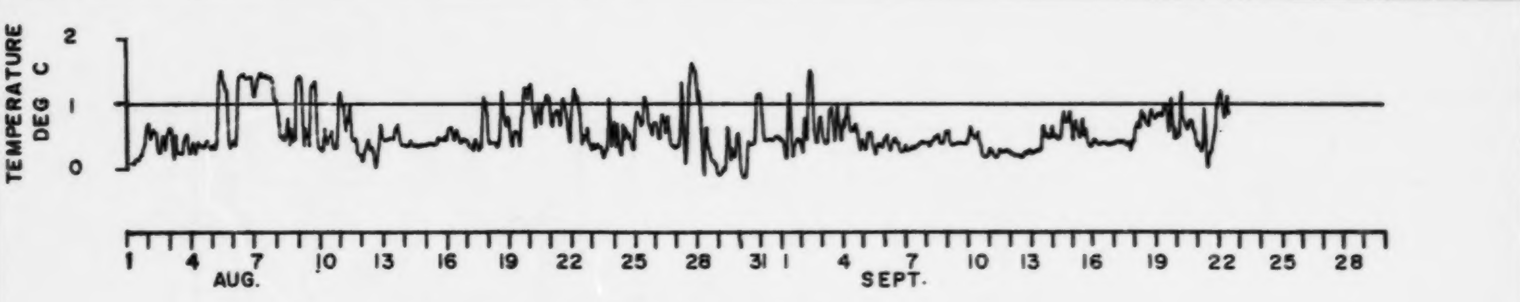
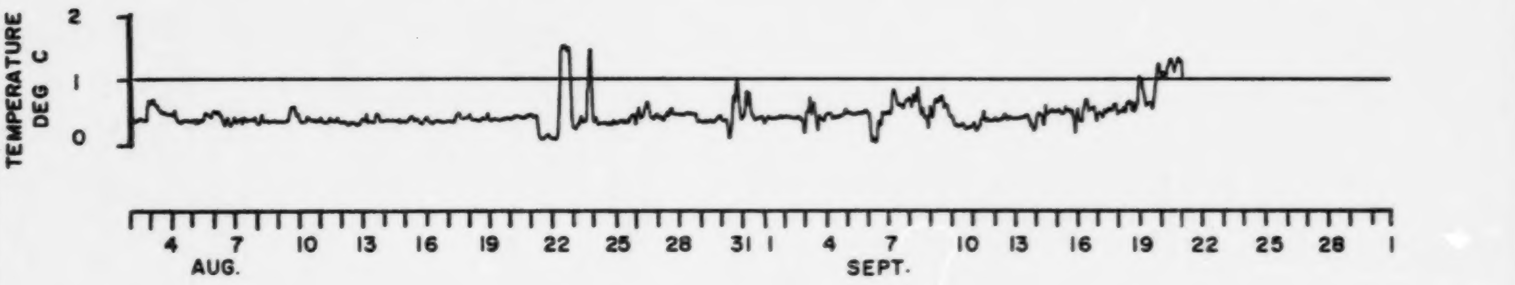


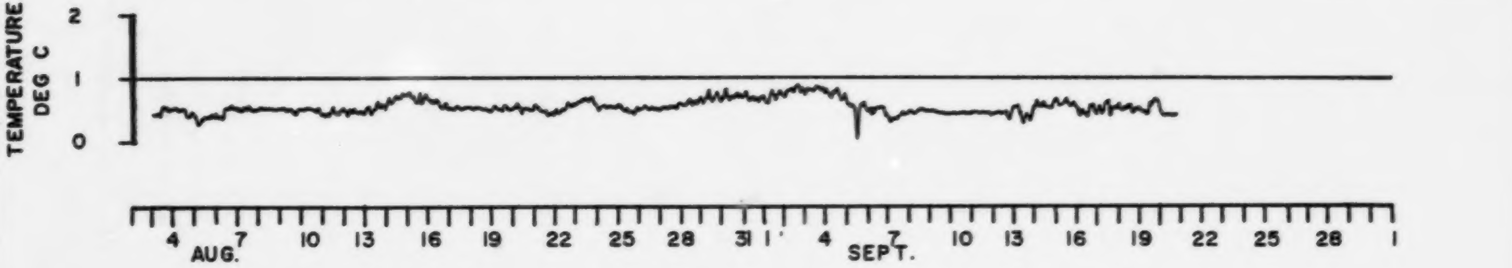
Figure 5.3-7 (c): Vertical cross-section of temperature along Lancaster Sound (c) September 13-29, 1979.



(a) MOORING H, 500 metres depth



(b) MOORING J, 500 metres depth



(c) MOORING K , 500 metres

Figure 5.3-8: Temperature time series at (a) mooring H, 500 m depth, (b) mooring J, 500 m depth, and (c) mooring K, 500 m depth, 1979.

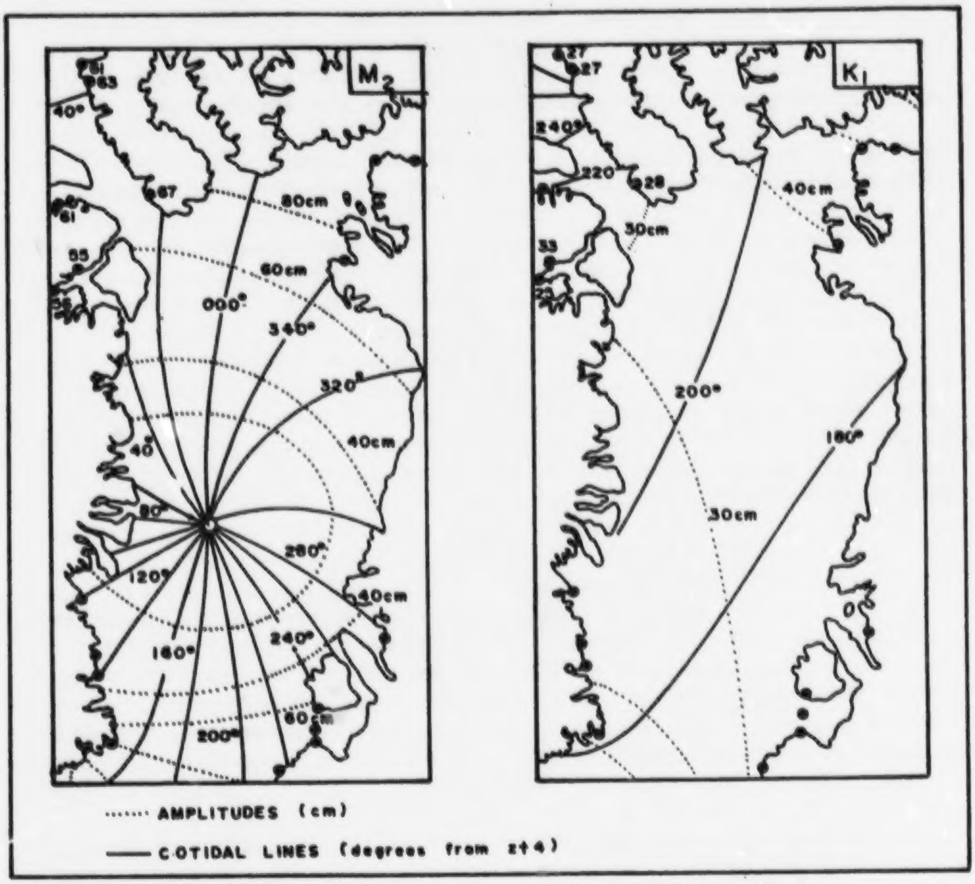

M2
40°
67
80cm
61
55
60cm
000°
340°
320°
40°
40cm
80°
280°
120°
40cm
240°
160°
60cm
200°
K1
27
27
240°
220
28
40cm
30cm
33
200°
160°
30cm
AMPLITUDES (cm)
COTIDAL LINES (degrees from z+4)

Figure 5.4-1: Tidal Heights of M_2 and K_1 constituents in Baffin Bay, after Godin (1966).

5.4 Tidal Currents

Oceanic tides can be divided into two modes: the barotropic or depth-independent mode associated with changes in sea level and the baroclinic or depth-dependent mode resulting from internal waves of tidal period. Tidal currents arise from both modes in varying proportions according to the location and depth.

Tidal oscillations occur at a series of discrete frequencies; the dominant oscillations are found in clusters at diurnal, semi-diurnal and longer period frequencies. The amplitude and phase of an oscillation occurring at a particular frequency is called a tidal constituent; the largest tidal constituents ranked according to the astronomical forcing potential are the semi-diurnal M_2 and diurnal K_1 constituents. Because of their lower frequencies and relatively low amplitudes in comparison with the synoptic variations, the long period tidal constituents require extended observational records for adequate resolution and will not be discussed further. Rather the spatial patterns of the largest of both the diurnal and semi-diurnal tidal constituents K_1 and M_2 will be examined in some detail.

5.4.1 Tidal Heights

Godin (1966) has compiled a map of the spatial variations of the M_2 and K_1 tidal height constituents as determined from sea level data collected at coastal measurement sites. These maps have been updated (Figure 5.5-4) using harmonic analyses of sea-level data measured since the time of Godin's paper, including a 10-month-long record of sea level variations measured in Johnson Bay on Devon Island, as part of the present study.

The M_2 tidal heights are largest in the northern portion of the study area with amplitudes of 80 cm, decreasing to approximately 60 cm in Lancaster Sound, with further decreases off the east coast of Baffin Island to effectively zero amplitude in the vicinity of an amphidromic point located off southeastern Baffin Island.

The K_1 tidal heights are more uniform throughout the study area with amplitudes of 25 to 33 cm, tending to decrease from north to south in western Baffin Bay.

5.4.2 Accuracy of Tidal Current Analysis

Errors in the tidal current analysis can result from three major sources. These are measurement errors in the current meter data, the presence of variations at harmonic constituent frequencies due to movements of the sub-surface moorings used to support the current meters and contamination of the harmonic analysis from variations due to phenomena other than tidal oscillations. The tidal analysis follows the methods of Godin (1972) using a computer program of Foreman (1978).

The measurement errors in the current speed and directional data as discussed in section 4 are + 1 cm/s for speeds up to 50 cm/s and from + 5 degrees to + 18 degrees for directions. These errors tend to be random rather than systematic and should be substantially reduced over the typical record lengths (50 days) used for the tidal analysis.

Errors due to mooring movement induced currents take two forms. First, there is the motion of the mooring itself. The amplitude of this motion was simulated from the pressure data for the uppermost current meter at station 6, a site of strong currents where vertical excursions of up to 45 m were observed. Using the pressure data to compute the vertical excursions and from this, the angle of mooring tilt, the horizontal velocities due to mooring motion were calculated and subjected to harmonic analysis. Amplitudes of 0.2 cm/s or less were computed at the frequencies of the dirunal and semi-diurnal tidal constituents.

In addition to the currents induced directly from the mooring motion, errors could arise from changes in the currents due to vertical excursions through zones of vertical current shears. Again, such an effect was simulated from the pressure data for the uppermost current meter at station 6 using the instantaneous mean shears between the uppermost and middle current meter records. For this simulation, the amplitude of the currents at the frequencies of the diurnal and semi-diurnal tidal constituents was 0.7 cm/s or less.

Other phenomena in addition to tidal currents can result in variations at the tidal frequencies. One very important such phenomenon is inertial oscillation, which at the latitudes of the study area has a frequency which lies among the semi-diurnal tidal constituents (see Figure 5.5-1). The amplitude of the inertial oscillations varies markedly with depth and is driven largely by fluctuations in the surface wind. At 35 m, the amplitude of inertial oscillations is typically 20 cm/s off the east coast of Baffin Island, the location of the largest observed inertial oscillations; at 250 m depth, they are reduced to levels of 3 to 4 cm/s (see section 5.5). Because of their short duration of 4 to 7 days and the fact that individual events have a random phase with one another, the contamination of tidal currents is reduced. Comparisons of the inertial oscillations with harmonic analysis results for station 13 indicates that the contribution of the inertial oscillations to the semi-diurnal frequency band is reduced by a factor of approximately two to four from the actual amplitude over a fifty-day record of currents.

Table 5.4-1

Parameters of the M_2 tidal current ellipse and information on the measurement sites as to location and period of data collection.

Station Id.	Lat.	Long.	Period Start	Period Stop	No. of Days	Depth (M.)	Semi Maj. (Cm/S)	Semi Min. (Cm/S)	Inclination Deg.	Phase Deg.
A	75°42'	77°52'	26/07/79	24/09/79	60	125	4.62	2.23	65.	158.
B	75°26'	76°21'	27/07/79	26/09/79	61	125	7.30	-.63	129.	43.
C	75°00'	79°09'	25/07/79	18/09/79	55	250	5.93	-.35	97.	23.
2	74°55'	78°41'	04/08/78	21/07/79	351	250	7.08	-.79	84.	36.
D	74°58'	78°29'	25/07/79	25/09/79	62	125	5.85	-.41	102.	32.
3	74°56'	76°53'	03/08/78	21/09/78	50	250	5.57	.47	143.	62.
1	74°35'	79°26'	04/08/78	21/07/79	343	250	1.89	.68	112.	172.
F	74°30'	79°12'	04/08/79	18/09/79	45	125	2.45	.85	72.	149.
10	74°31'	77°19'	03/08/78	28/09/78	57	250	4.74	.94	146.	69.
4	74°30'	80°38'	05/08/78	17/09/78	43	250	4.50	-.49	179.	93.
5	74°09'	80°19'	06/08/78	29/08/78	23	250	3.97	.19	4.	103.
6	74°26'	81°55'	01/08/79	22/09/79	52	250	4.58	.26	10.	113.
77-1	74°05'	81°11'	29/07/79	29/09/79	62	250	3.98	-.21	5.	100.
H	74°07'	82°11'	01/08/79	22/09/79	52	250	3.94	-.33	177.	119.
J	74°09'	82°54'	02/08/79	20/09/79	49	500	2.10	.78	159.	87.
K	74°08'	83°21'	03/08/79	20/09/79	48	500	1.86	.48	24.	127.
I	73°50'	82°08'	02/08/79	22/09/79	51	500	3.64	.15	179.	109.
O	73°37'	81°05'	12/08/79	12/09/79	31	250	1.21	.46	112.	118.
L	73°52'	80°11'	29/07/79	18/09/79	51	500	3.08	.52	167.	88.
M	73°47'	80°15'	29/07/79	21/09/79	54	250	3.54	.60	152.	73.
8A	73°45'	78°47'	29/09/78	28/07/79	302	250	4.86	-.10	177.	92.
8	73°42'	78°11'	01/08/78	27/09/78	58	250	7.22	-1.10	157.	71.
7	74°07'	78°29'	02/08/78	16/09/78	45	250	4.53	.01	164.	86.
N	74°03'	78°12'	05/08/79	26/09/79	52	250	3.02	.58	156.	84.
9	74°07'	77°25'	02/08/78	28/09/78	57	250	5.41	-.53	168.	82.
P	72°49'	77°02'	11/08/79	04/09/79	23	250	5.22	-.01	168.	65.
11	72°23'	74°04'	11/08/78	26/09/78	47	125	5.75	-.83	163.	81.
13	72°31'	72°46'	11/08/78	08/08/79	362	250	3.49	.13	145.	71.
Q	71°40'	71°01'	10/08/79	01/10/79	53	125	2.47	-.39	102.	174.
R	71°46'	70°45'	09/08/79	01/10/79	53	250	2.33	.72	139.	38.

In addition to inertial oscillations, other variations are present at semi-diurnal and diurnal frequencies along with the tidal currents themselves. This is best illustrated from the auto-spectra of currents (see section 5.1) which shows background levels of variations through the diurnal and semi-diurnal frequency bands. Part of the background variations are due to random measurement errors discussed above. The background spectral energy varies according to location and depth, and appears to increase at sites of large synoptic spectral energy peaks. At nominal depths of 35 m, the largest background levels are 1.2 cm/s (stations 4 and 6). The background decreases with increasing depth: at 250 m and 500 m background levels are 0.8 cm/s or less.

To summarize, the accuracy of the tidal analysis is limited by measurement errors, contamination due to mooring motion and other oceanic phenomena, such as inertial oscillations. At 35 m depth, the errors due to inertial oscillations can be so large that the semi-diurnal tidal analysis is invalid. At greater depth, the effect of inertial oscillations is greatly reduced to levels of 2 cm/s or less. Combining the errors due to mooring motion and background variations $[(0.2^2+0.7^2+1.2^2)\ ]$ results in errors of 1.4 cm/s or less for 35 m depth. For depths of 250 m or greater, the corresponding computation yields a value of 1.0 cm/s or less.

5.4.3 M_2 Tidal Currents

As first approach to examining the spatial variations of the M_2 tidal currents, a map of the results of the harmonic analyses is presented in Figure 5.4-2. At each measurement location, the tidal current ellipse is displayed; the harmonic analysis program decomposes the tidal currents into two oppositely rotating vectors the sum of which trace out an ellipse. The semi-major axis of the ellipse represents the maximum amplitude of the tidal current, while the inclination denotes the angle between the direction of maximum tidal flow and true east, in degrees counter-clockwise (as listed in Table 5.4-1).

The amplitude of the M_2 tidal currents has a range of 4.4 to 7.2 cm/s east of Devon Island and Lancaster Sound. Proceeding westward through Lancaster South, the M_2 current amplitudes decrease from approximately 4 cm/s at the mouth of the Sound to approximately 2 cm/s some 100 km into the Sound. The M_2 tidal currents decrease to the south in western Baffin Bay; off Cape Adair on the east coast of Baffin Island, the amplitudes are only 2 to 3 cm/s, while in Pond Inlet, the M_2 tidal current has an amplitude of 5 cm/s and is less than 2 cm/s in Navy Board Inlet.

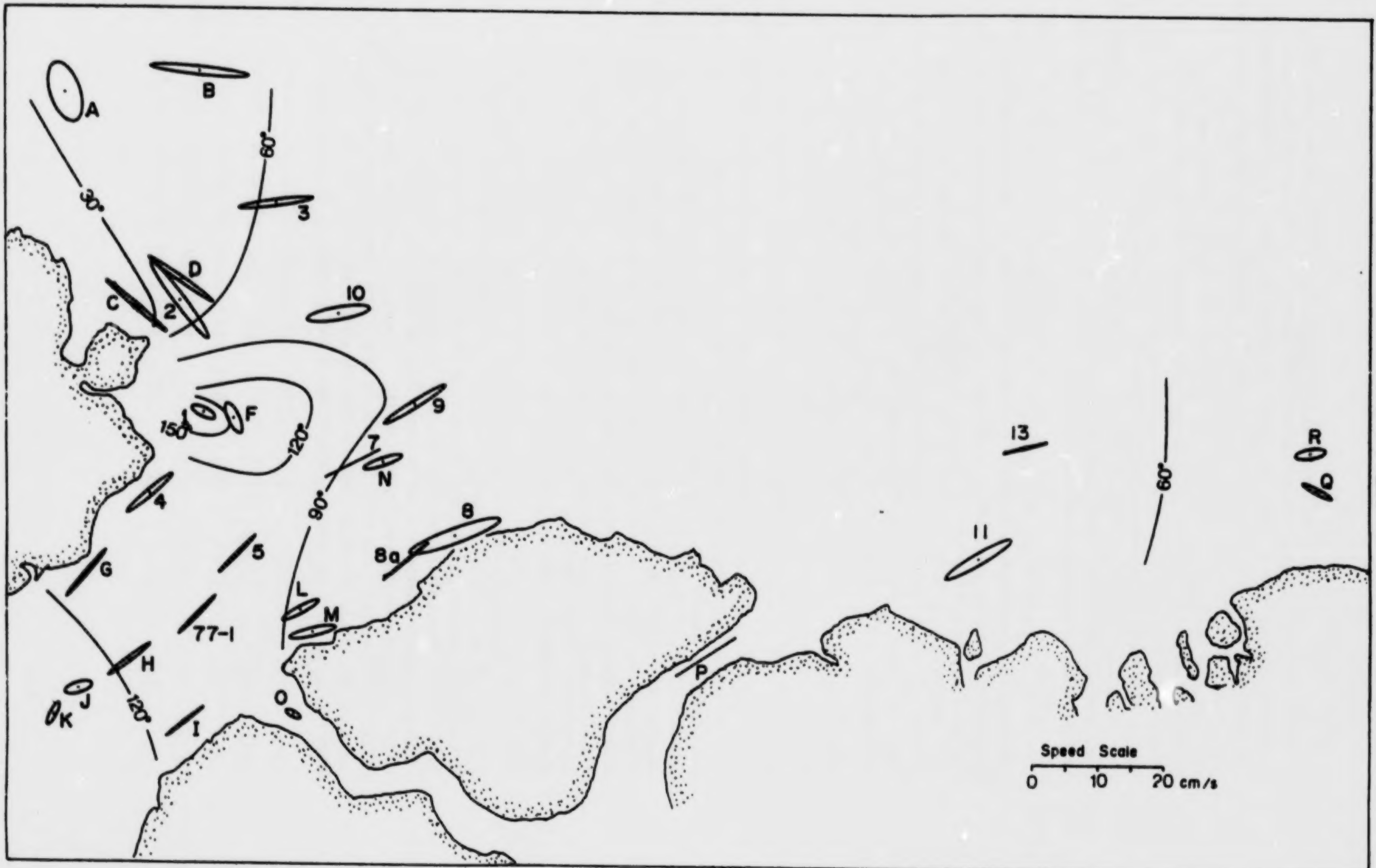

A
B
30°
60°
3
D
C
2
10
150
F
120°
9
7
N
90°
4
8
8a
5
G
L
M
77-1
H
J
K
120°
I
O
P
13
11
60°
R
Q
Speed Scale
0
10
20 cm/s

Figure 5.4-2: M_2 tidal current ellipses for current meter data.

A comparison of the phases of the M_2 tidal heights with tidal currents indicates that the M_2 tide has the characteristics of a standing wave in eastern Lancaster Sound with the tital currents lagging tidal heights by only 20 degrees. Off eastern Devon Island and eastern Baffin Island the phase of the M_2 currents lags the tidal heights by 60-100 degrees, suggesting that the M_2 tide in these regions may be more similar to a progressive wave.

Anomalous M_2 tidal currents appear off southeast Devon Island (stations 1 and F). Here the amplitudes are noticeably lower (1.9 and 2.4 cm/s) than in adjacent areas. As well, the phases are anomalously larger, being 50 degrees or greater than any nearby measurement sites. This may be due to a transition from the tidal current regimes of northwestern Baffin Bay to that of Lancaster Sound.

5.4.4 K_1 Tidal Currents

Using the same analysis procedures, a map of the K_1 tidal currents is presented in Figure 5.4-3 based largely on 250 m observations. For the K_1 results, analysis from 35 m data are included if no other measurements are available (station E) since inertial oscillations do not affect the K_1 tidal currents. As for the M_2 tidal currents, the orientation of the K_1 tidal currents tends to parallel the coastline for locations close to the coastline. For example, at the current meter moorings off Philpots Peninsula, the K_1 tidal currents are orientated east-west 70 km offshore; with decreasing distance from the coastline, the orientation increasingly turns more to north-south.

As for the M_2 tidal currents, the K_1 tidal currents strengthen in Lancaster Sound as compared to northwestern Baffin Bay. Typical amplitudes of 2.5 to 3.5 cm/s are measured off eastern Devon Island and the mouth of the Sound. In Lancaster Sound, the K_1 tidal currents have amplitudes of 5 to 8 cm/s, with largest values occurring on the sides of the Sound as compared to mid-Sound locations. Off the east coast of Baffin Island, south of Pond Inlet, the K_1 tidal currents become extremely small, less than 1.5 cm/s, and cannot be resolved from the background noise levels. The K_1 tidal currents in both Navy Board Inlet and Pond Inlet are small as well with amplitudes of 2.2 and 1.5 cm/s, respectively.

The K_1 tide appears to behave as a standing wave east of Devon Island, the phases of the tidal heights and tidal currents differing by only 20-30 degrees over the areas where measurable K_1 tidal current oscillations occur. In eastern Lancaster Sound, the wave characteristics are intermediate between standing and progressive waves.

Table 5.4-2

Parameters of the K_1 tidal current ellipse and information on the measurement sites as to location and period of data collection.

Station	Lat.	Long.	Period		No. of	Depth	Semi		Inclination	Phase
Id.			Start	Stop	Days	(M.)	Maj.	Min.	Deg.	Deg.
							(Cm/S)			
A	75°42'	77°52'	26/07/79	24/09/79	60	125	1.85	-.73	16.	110.
B	75°26'	76°21'	27/07/79	26/09/79	61	125	1.63	-1.02	11.	65.
C	75°00'	79°09'	25/07/79	18/09/79	55	250	2.37	-.05	91.	109.
2	74°55'	78°41'	04/08/78	21/07/79	351	250	3.64	-.44	58.	113.
D	74°58'	78°29'	25/07/79	25/09/79	62	125	2.40	-.20	65.	117.
E	74°59'	77°52'	25/07/79	25/09/79	62	35	2.86	-1.52	47.	109.
3	74°56'	76°53'	03/08/78	21/09/78	50	250	2.96	-1.51	21.	118.
1	74°35'	79°26'	04/08/78	21/07/79	343	250	4.68	-.46	23.	183.
F	74°30'	79°12'	04/08/79	18/09/79	45	125	3.53	-.01	33.	125.
10	74°31'	77°19'	03/08/78	28/09/78	57	250	2.85	1.39	25.	121.
4	74°30'	80°38'	05/08/78	17/09/78	43	250	7.01	.15	25.	146.
5	74°09'	80°19'	06/08/78	29/08/78	23	250	5.61	.69	1.	134.
G	74°26'	81°55'	01/08/79	22/09/79	52	250	8.03	.22	5.	134.
77-1	74°05'	81°11'	29/07/79	29/09/79	62	250	4.76	.14	1.	133.
H	74°07'	82°11'	01/08/79	22/09/79	52	250	5.56	.31	177.	140.
J	74°09'	82°54'	02/08/79	20/09/79	49	500	5.86	.30	177.	140.
K	74°08'	83°21'	03/08/79	20/09/79	48	500	5.45	.34	10.	146.
I	73°50'	82°08'	02/08/79	22/09/79	51	500	6.59	-.01	4.	136.
O	73°37'	81°05'	12/08/79	12/09/79	31	250	2.25	.27	115.	134.
L	73°52'	80°11'	29/07/79	18/09/79	51	500	4.06	-.56	160.	151.
M	73°47'	80°15'	29/07/79	21/09/79	54	250	7.64	-.82	158.	139.
8A	73°45'	78°47'	29/09/78	28/07/79	302	250	3.36	.01	178.	125.
8	73°42'	78°11'	01/08/78	27/09/78	58	250	4.84	.60	168.	176.
7	74°07'	78°29'	02/08/78	16/09/78	45	250	3.53	-.29	3.	134.
N	74°03'	78°12'	05/08/79	26/09/79	52	250	2.70	-.41	6.	134.
9	74°07'	77°25'	02/08/78	28/09/78	57	250	2.43	-.55	179.	131.
P	72°49'	77°02'	02/08/79	01/10/79	50	35	1.47	-.79	2.	269.
11	72°23'	74°04'	11/08/78	26/09/78	47	125	1.25	-.31	109.	302.
13	72°31'	72°46'	11/08/78	08/08/79	362	250	.51	.10	125.	344.
Q	71°40'	71°01'	10/08/79	01/10/79	53	125	.48	.04	179.	260.
R	71°46'	70°45'	09/08/79	01/10/79	53	250	.32	-.18	79.	232.

5.4.5 Internal Tides

To this point, the discussion has concentrated on spatial variations of tidal currents at similar depths. In addition tc the horizontal spatial changes, vertical changes in the tidal currents occur due to internal tides. The most commonly accepted opinion concerning the generation mechanism for internal tides is that they"... represent the response to the forcing of isopycnal surfaces over topographic features by the surface tide." (Wunsch, 1975). The changes in the internal tidal current amplitude with depth depend on the local density stratification: the largest changes occur over depths of the greatest vertical density gradients. In the study area, the largest density gradients occur in the uppermost 100 m with appreciable changes extending to depths of approximately 300 m.

Because of the high latitude of the study area, all of the internal tidal constituents in the diurnal group of frequencies and some of those in the semi-diurnal group, will be poleward of the inertial latitude (Figure 5.5-1). As a result, freely travelling internal waves are not expected to occur at the frequency of these constituents. However, internal tides can occur locally as trapped waves over the varying bottom bathymetry.

Detection of internal M_2 tides is made difficult due to the contamination of the tidal analysis by inertial oscillations in the upper portion of the water column. However, the K_1 tidal currents are more condusive to searching for internal tides.

At locations in Lancaster Sound, the variation of the tidal currents is relatively uniform with depth (within 38% at stations 77-1, 77-3, G, H, I and J). In northwestern Baffin Bay, the reduced levels of the K_1 tidal currents make meaningful comparisons with depth difficult. However, a large vertical variation of the K_1 tidal currents is evident at locations off the N.W. coast of Bylot Island, in the vicinity of Cape Hay (see Figure 5.4-4). The K_1 amplitude at station M decreases from 15.0 cm/s at 64 m to 7.6 cm/s at 244 m to 2.5 cm/s at 476 m. The changes with depth decrease with distance offshore, as measured at stations 6 and L, but remain significant. Thus internal K_1 tides may be of considerable importance in local areas; however, they do not appear to be significant in much of the offshore study area.

5.4.6 Tidal Currents in Nearshore Zones

The description of the tidal currents presented above has been based on observations collected at considerable distances from the coastline (3 to 84 km). Tidal currents may be considerably larger in the shallower water of nearshore zones. Evidence of the amplification of the K_1 tidal currents due to internal tides was presented above; however, the nearest shore data was collected in water depths exceeding 500 m.

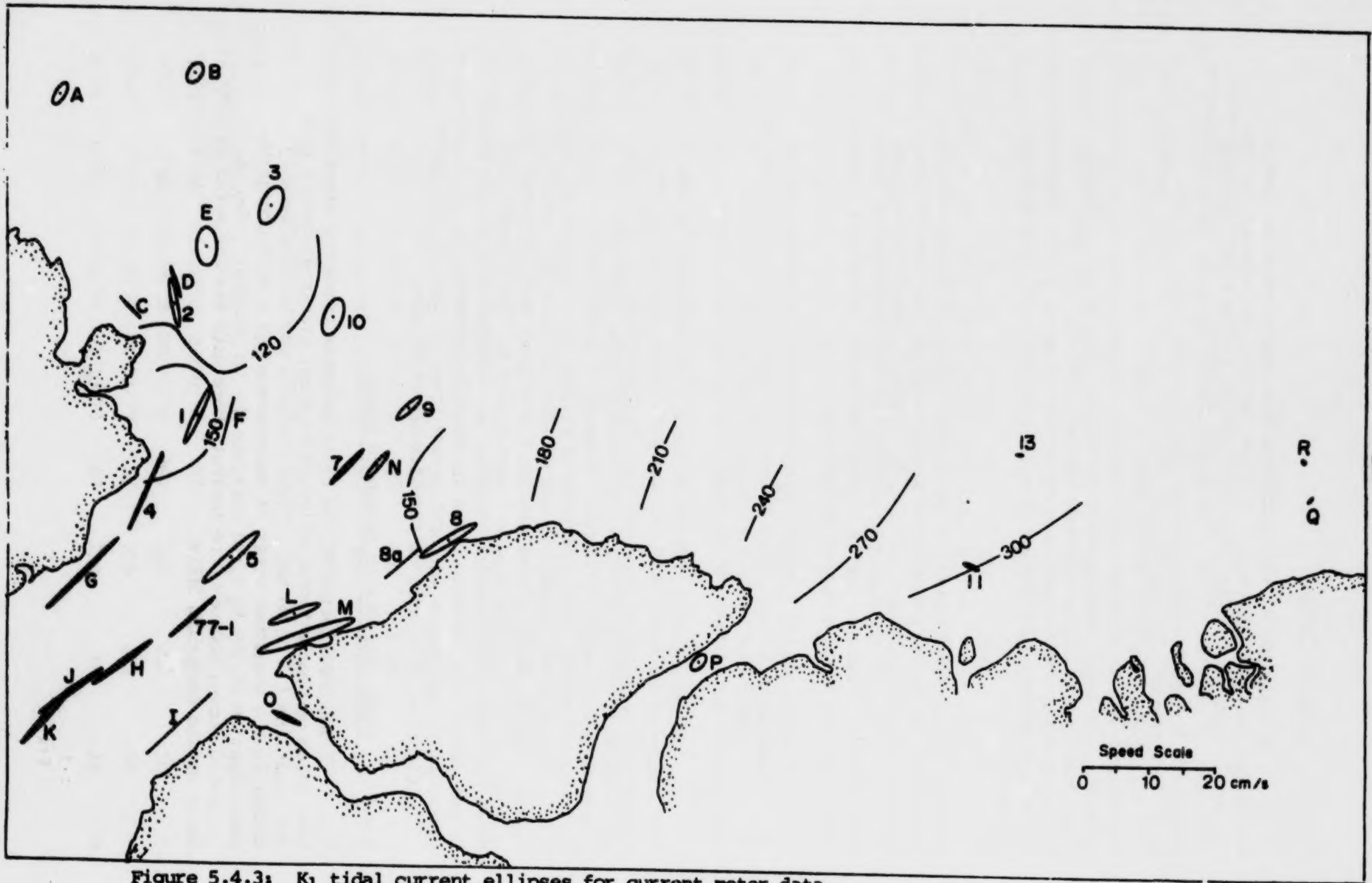

A
B
3
E
D
C
2
10
120
1
150
F
9
7
N
180
210
13
R
4
150
8
240
Q
8a
5
G
270
300
11
L
M
77-1
J
H
P
O
I
K
Speed Scale
0
10
20 cm/s

Figure 5.4.3: K_1 tidal current ellipses for current meter data.

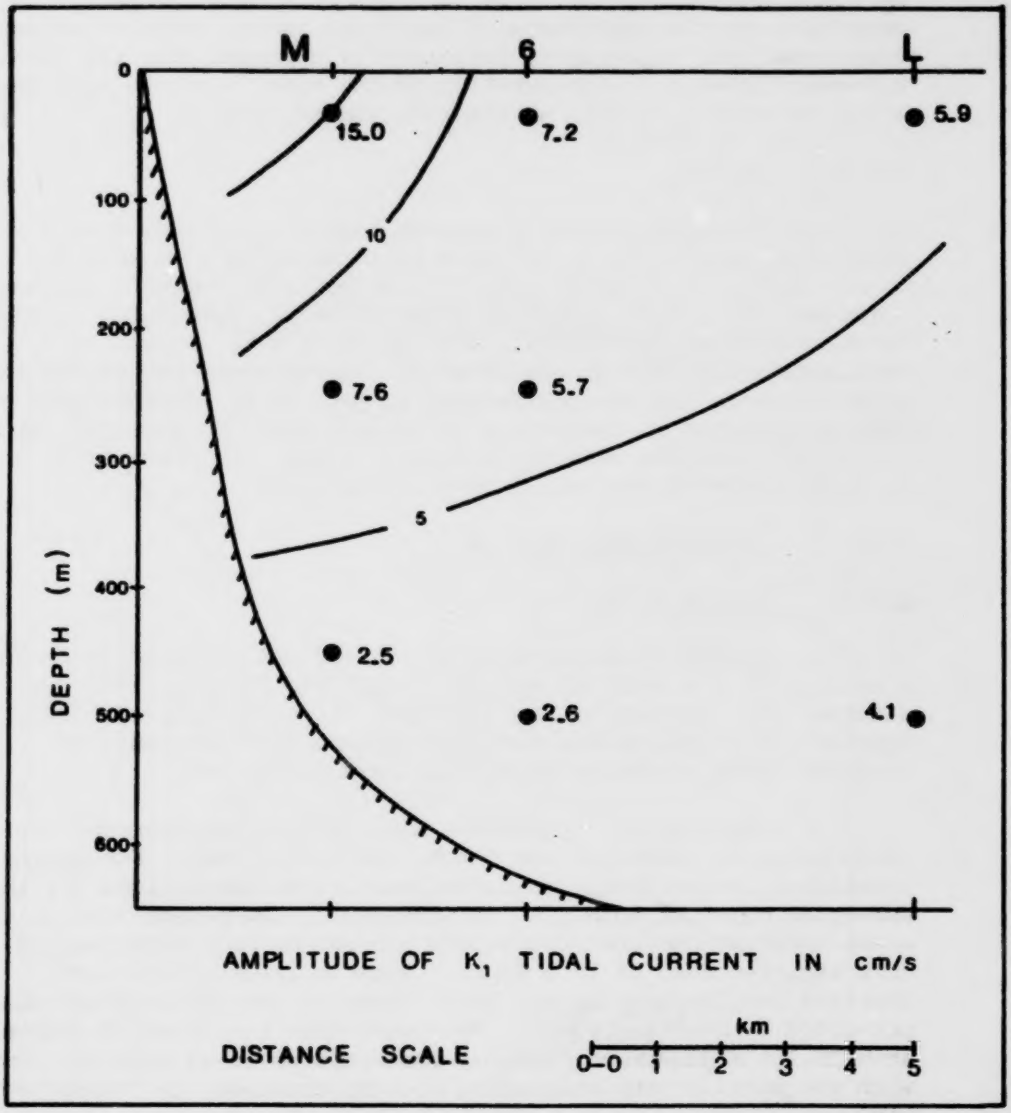


Figure 5.4.4: Variations of the amplitude of the K_1 tidal currents with depth and distance offshore of northwestern Bylot Island.

In 1974, the Canadian Hydrographic Service measured currents at 73°43.0'N 84°48.6'W, off Cape Crauford on Brodeur Peninsula in Lancaster Sound in a water depth of 85 m. This time series record, when subjected to harmonic analysis, yielded K_1 and M_2 tidal current amplitudes of 18.5 and 20.8 cm/s, respectively, several times the amplitudes of the tidal constituents at offshore locations. The topographic influence is apparent from the good agreement between the orientation of the tidal currents with the local bathymetry as well as the enhanced amplitudes.

5.4.7 Summary

The tidal currents through much of the study area are relatively small with K_1 and M_2 amplitudes being less than 8.0 cm/s. Since the areas of large K_1 and M_2 tidal currents did not coincide, the largest offshore tidal currents represented as the sum of the two major constituents are typically 8 to 10 cm/s in amplitude and do not exceed 12 cm/s. In nearshore locations, the tidal currents can be considerably larger. A K_1 internal tide off Cape Hay results in amplitudes of 15 cm/s near the surface. At a location in shallow water in Lancaster Sound, the combined K_1 and M_2 tidal currents reached 38 cm/s in amplitude.

5.5 Inertial Oscillations

5.5.1 Introduction

Inertial oscillations are variations in water currents occurring at the inertial frequency of 2 sin ϕ revolutions per sidereal day, where ϕ is the latitude. In their simplest form, inertial oscillations are circular motions with the sense of rotation being clockwise in the northern hemisphere.

Inertial period motions have been widely observed over a large range of latitudes and depths (Webster, 1968). For northern locations, Saelen (1963) measured inertial-period motions off the Norwegian coast at 63°N. As an atmospheric low passed through the area, inertial oscillations with a typical current magnitude of 15 cm/s were recorded at 10 m depth. Some indirect evidence of inertial oscillations in the upper layer of the Arctic Ocean was presented by Hunkins (1967). He showed that ice island T-3 located at 83°N 156°W underwent inertial oscillations of 10 cm/s amplitude with the oscillations coinciding with fluctuations in the surface wind.

5.5.2 Analysis Techniques

One of the difficulties of measuring inertial oscillations in polar regions arises because the inertial period in those regions is near 12 hours, within the range of periods of semi-diurnal tidal constituents (see Figure 5.5-1). To adequately resolve the inertial

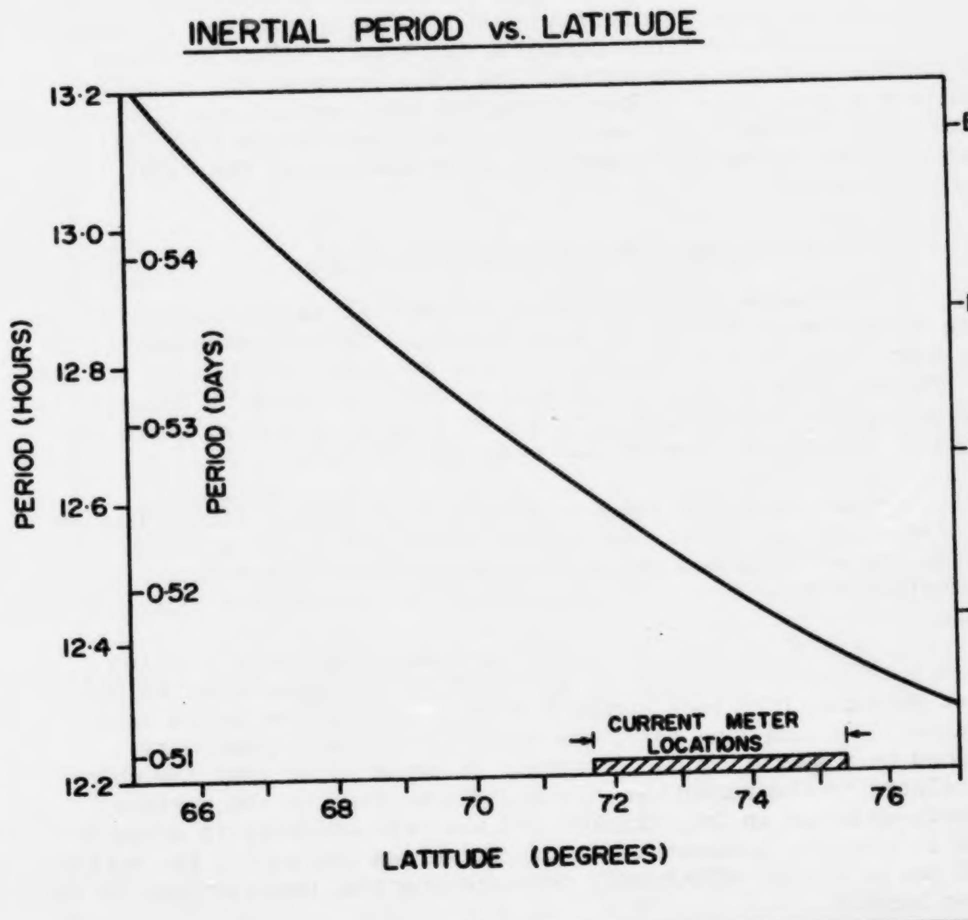


Figure 5.5.-1: The period of inertial oscillations as a function of latitude.

oscillations from tidal variations requires a long record of current observations to attain the necessary frequency resolution. However, because the inertial oscillations often occur as individual events, with the phase of the events being unrelated to one another, oscillations must be resolved over a record length comparable to the length of individual events; thus, inertial oscillations are difficult to extract even from long records.

In the area of this study, tidal currents are relatively small with the largest tidal constituent (M_2) having current magnitudes on the order of 1.2 to 8 cm/s, depending on the location (see Section 5.4). If inertial oscillations are present which are significantly larger than the amplitude of the local semi-diurnal tidal constituents, it should be possible to detect them. Furthermore, it is possible to remove much of the tidal currents at those stations where long (~1 year) time series of currents exist. This is achieved by using standard harmonic analysis programs (Foreman, 1978) to predict the tidal currents, and then subtracting these variations from the time series. In short records, the harmonic analysis algorithm is unable to resolve the inertial oscillations from tidal oscillations. With longer time series the inertial oscillations become less important in contaminating the tidal analysis results.

5.5.3 Inertial Oscillations at station 78-13

We begin our examination of inertial oscillations with the data from station 78-13. At this location, current measurements of 362 days duration are available at nominal depths of 35, 250 and 500 m. The measurement site is located at latitude 72°31' N about 75 km off the east coast of Baffin Island at a depth of 840 m, where the M_2 tidal constituent has an amplitude of 3.5 cm/s.

Starting with the decimated hourly data, a finite impulse recursive digital filter was applied which passed all current variations with periods between 1.5 and 2.5 cycles per day, (hereafter referred to as the SD filter, see Figure 5.5-2).

A plot of the band-passed current revealed a striking difference in the amplitude of semi-diurnal variations before and after November 1978 (see Figure 5.5-3A). During the period from November 1978 and June 1979, the semi-diurnal variations were reduced by a factor of two or more. It seems clear that the change is related to the formation of a solid ice cover at the surface (freeze-up began in late October and was well underway in November 1978). With the presence of an extensive sea ice cover, the surface wind can no longer effectively generate inertial oscillations in the water beneath.

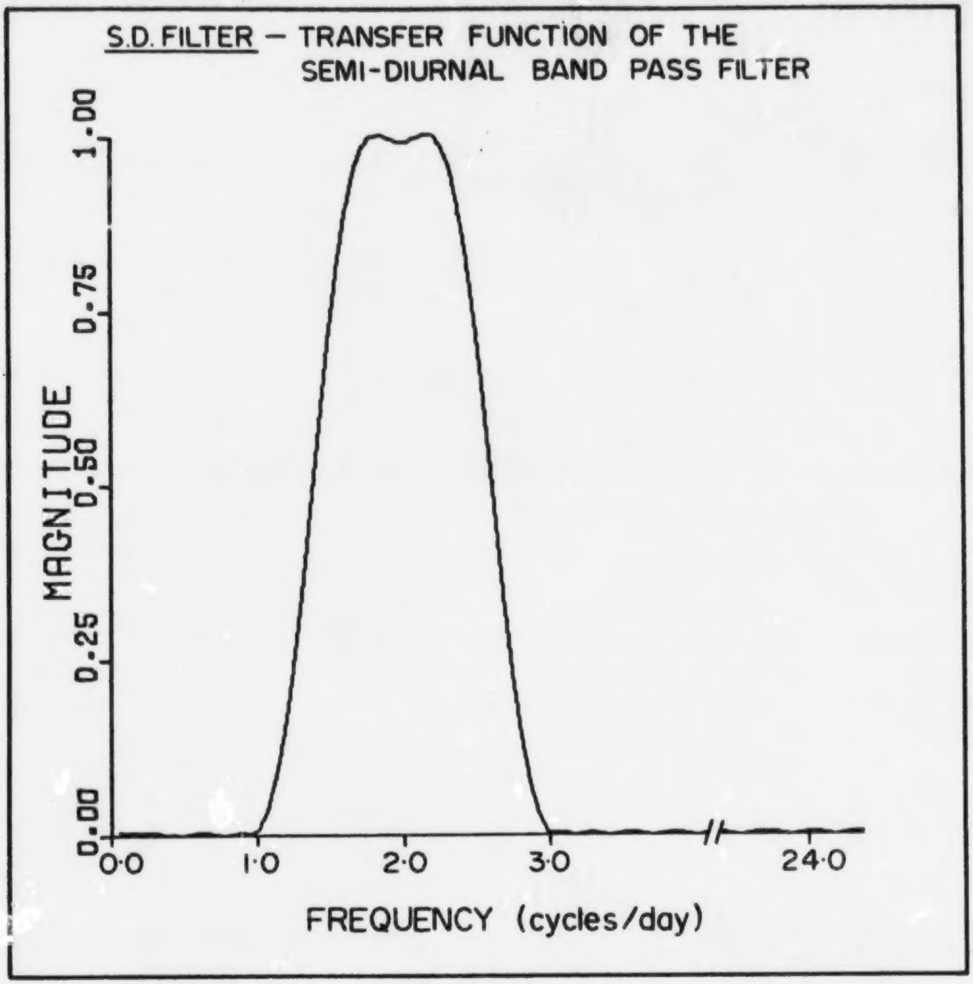


Figure 5.5-2: The transfer function of the semi-diurnal band pass filter used in the analysis of inertial oscillations.

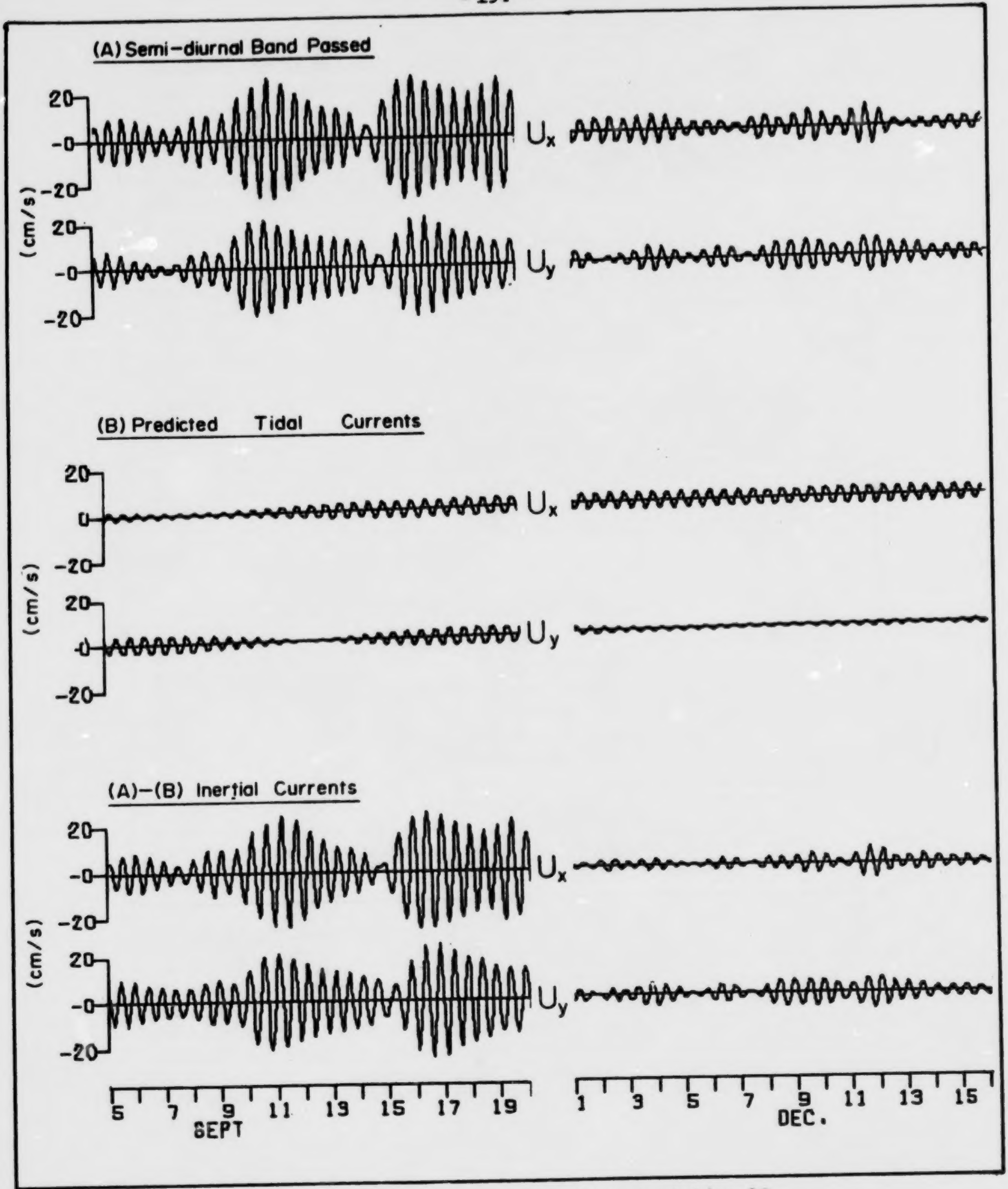


Figure 5.5-3: For the current meter time series data at station 13, 35 m depth, (a) the semi-diurnal passed data, (b) the predicted semi-diurnal tidal current and (c) the difference between (a) and (b) dominated by inertial oscillations.

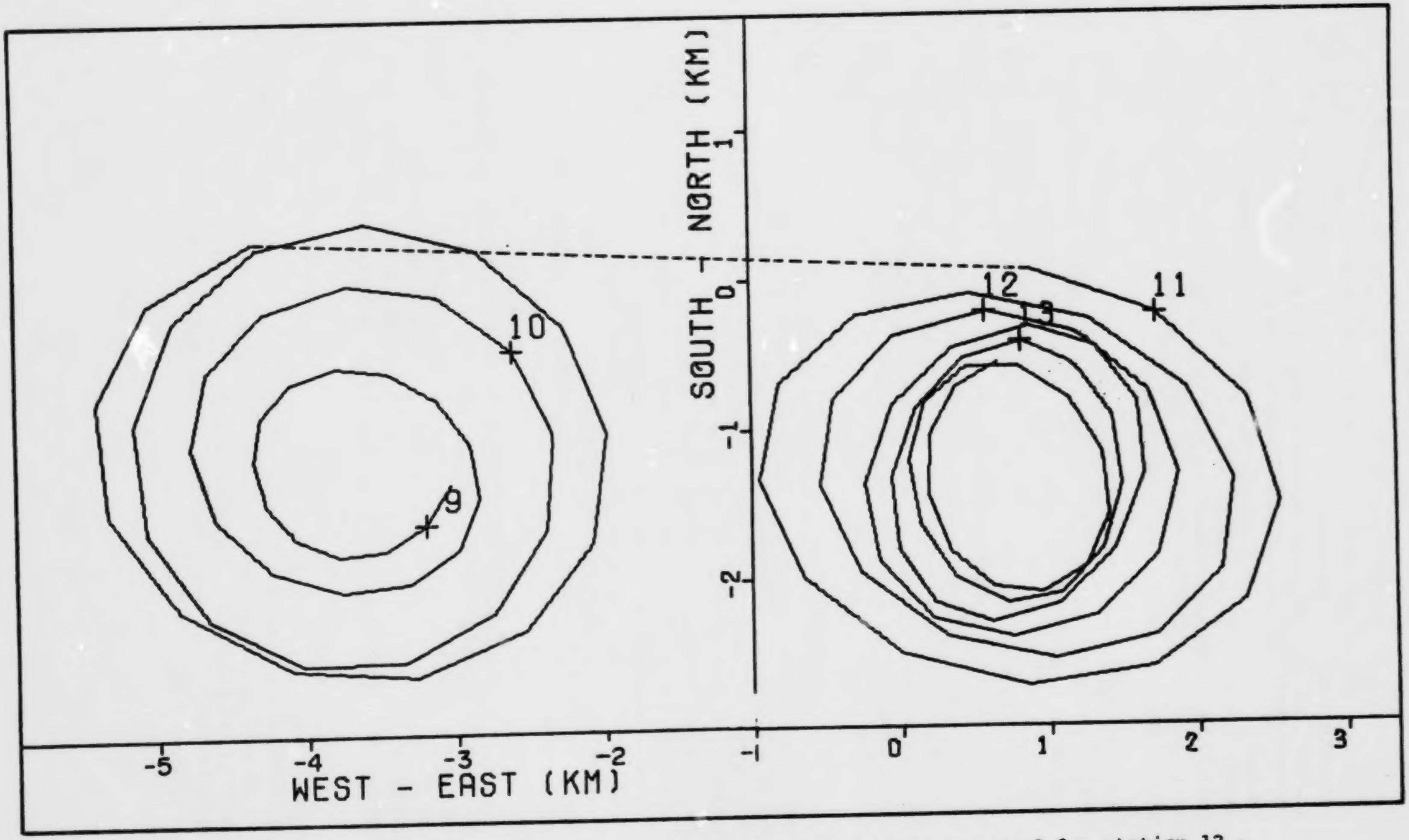


Figure 5.5-4: Progressive vector diagram of the inertial oscillations computed for station 13 - 35 m depth from September 9-14, 1978.

It is possible that the changes in the surface wind could generate inertial oscillations in the ice cover which in turn could induce inertial oscillations in the upper water layers. The inertial oscillations of ice Island T-3 are an example of this (Hunkins, 1967). The reduced amplitudes of the inertial oscillations at 35 m depth observed in the present study suggest that this mechanism is much less effective in generating inertial oscillations at the level of the uppermost current meter than the direct forcing due to the surface wind.

To better delineate the inertial oscillations, a harmonic analysis was made of the SD band-passed currents over the period November 15, 1978 to June 30, 1979, when the analysis is least likely to be contaminated by inertial oscillations. From this analysis, predictions of the semi-diurnal tidal currents were produced for the entire 362 day period of the SD band passed time series (figure 5.5-3B). After subtracting the predicted tidal currents from the band-passed currents, the resultant time series represent inertial oscillations along with other semi-diurnal variations due to measurement errors and unresolved internal tidal currents.

Inertial oscillations are readily apparent in the time series plots for the period prior to freeze-up. These oscillations occur as individual events of, typically five to seven days duration. An example of one such event from Sept. 9 - 14, 1978 is shown in Figure 5.5-4, in the form of a progressive vector diagram as computed from the band-passed currents, following removal of the tidal currents. The inertial oscillations trace out clockwise circular motions, as expected, beginning with a period of growth (Sept. 9-10) followed by a period of decay (Sept. 11-14). The diameter of the inertial oscillations is typically 2 km and occasionally approaches 4 km during the peak oscillations of a strong event.

In Figure 5.5-5a, the percent exceedance is presented for the speeds of the band-passed currents after removal of the tidal currents. For the open water period, the maximum speed is 30 cm/s and 10 percent of the values exceed 17 cm/s. In contrast, the speeds calculated during the ice covered period are much reduced; the maximum speed is 8 cm/s and the 10 percent level is only 4 cm/s.

To examine the behavior of inertial oscillations at greater depths, the same analysis techniques were applied to measurements collected at 250 m depth. The results of the analysis are presented in the form of a percent exceedance diagram for the inertial oscillations (figure 5.5-5b). The magnitude of inertial oscillations is markedly reduced at this depth with a maximum calculated speed of only 12 cm/s.

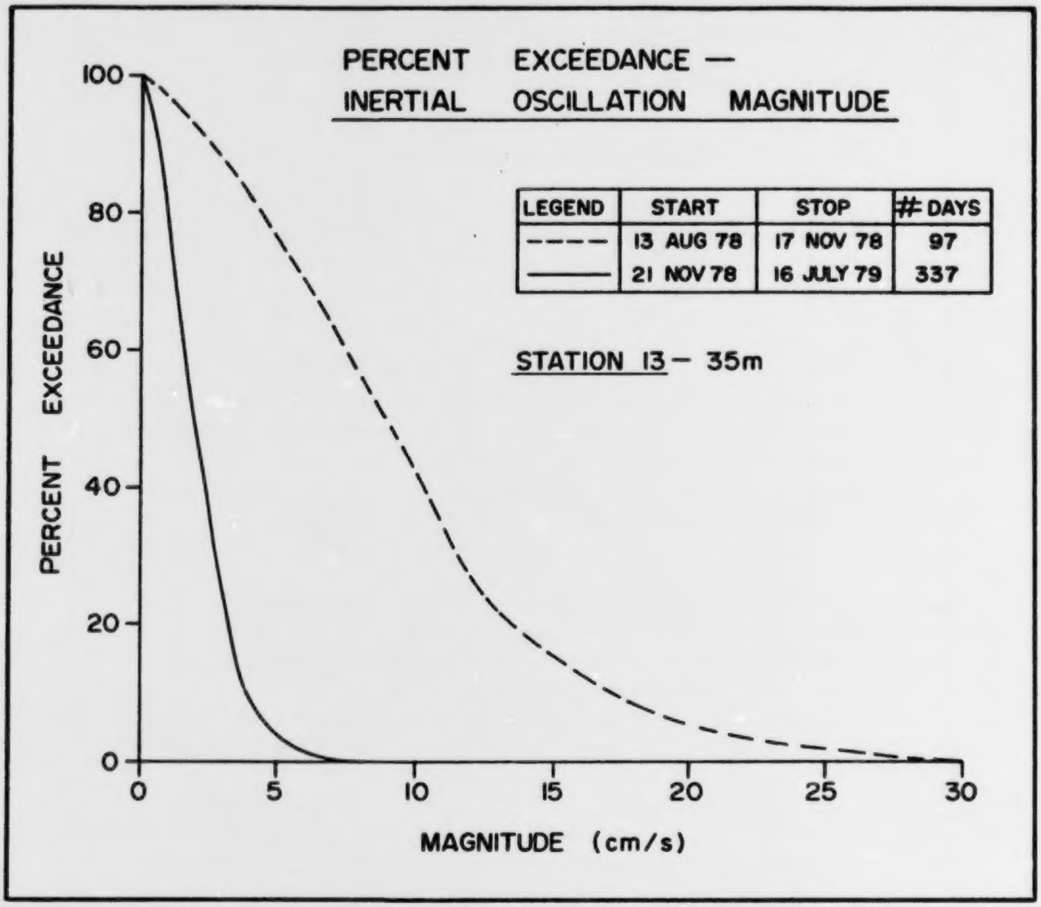


Figure 5.5-5(a): The percent exceedance of inertial oscillation magnitudes at (a) station 13, 35 m depth.

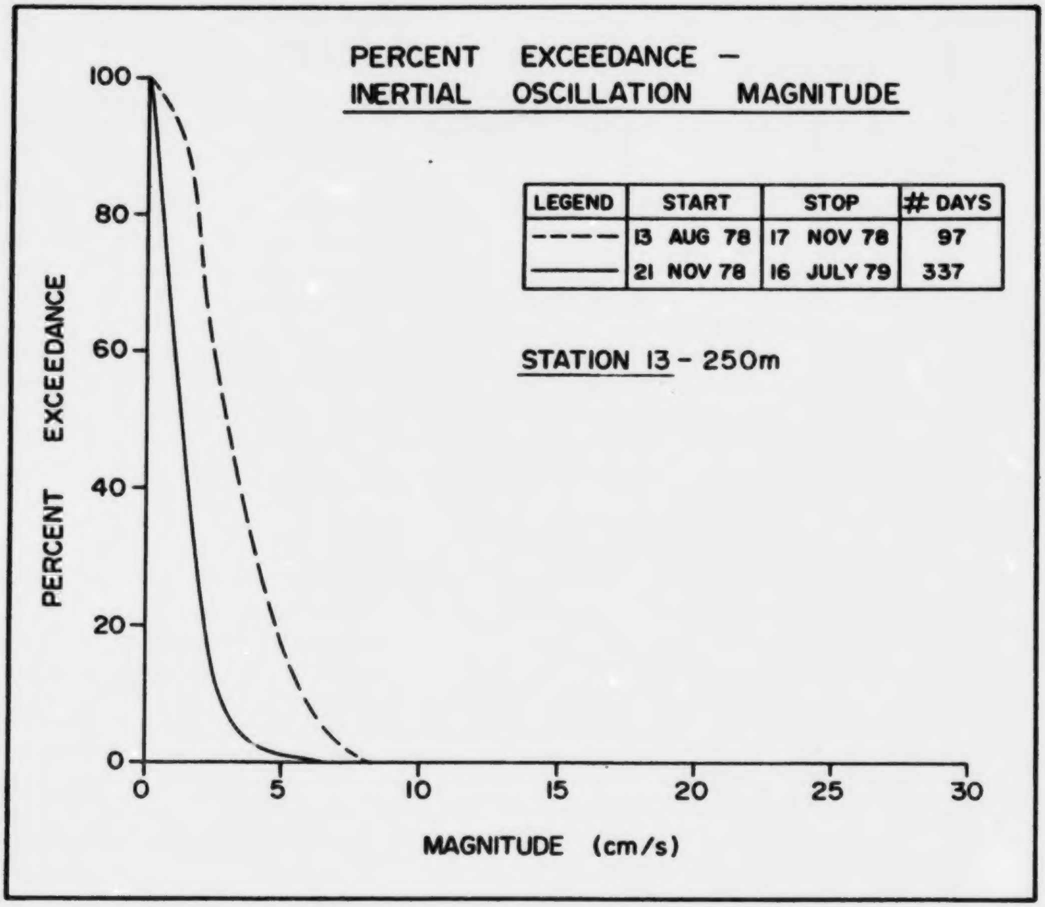


Figure 5.5-5(b): The percent exceedance of inertial oscillation magnitudes at (b) station 13, 250 m depth.

There is no apparent matching in the times of occurrance of inertial oscillations events at 35 m and 250 m. Nevertheless, a portion of the inertial oscillations at 250 m was related to surface processes since significantly larger amplitudes were found in the open water period as compared to ice-covered periods (figure 5.5-5b).

5.5.4 Inertial Oscillations off Eastern Baffin Island

We have examined the inertial oscillations at station 13 in some detail. To extend the description over a larger area and to study the horizontal coherence of inertial oscillations, we now consider the current measurements at four sites located east of Baffin Island in the summer of 1978: stations 11, 14, and 15 along with station 13. In this analysis, the tidal currents cannot be effectively removed since the current meter records are of a shorter duration (50 days) and limited to periods of open water. Instead, the northerly component of the band-passed currents are presented in Figure 5.5-6. Based on the harmonic analysis at station 13, the root-mean-square value of the northerly component of the semi-diurnal tidal currents is only 1.5 cm/s with a maximum value over 362 days of 4.7 cm/s.

Inertial oscillations are clearly evident in the band-passed currents at each measurement site off Baffin Island (Figure 5.5-6). The inertial oscillations can be distinguished by tidal currents by the relatively large magnitudes of the northerly componentes as compared to the expected tidal currents, and by the irregular bursts of activity in the semi-diurnal variations.

When visually scanning the time series plots, there appears to be little horizontal coherence in the level of inertial oscillations among the four sites. Often large inertial oscillations will occur at one location with only low-to-moderate levels at the other locations over the same time period. One example of such an occurrence is found on September 9-14 when strong inertial oscillations were measured at Station 13 (Figure 5.5-4) while the levels of inertial oscillations at the other three stations were relatively low. This lack of any evident coherence applies to all pairs of stations including stations 14 and 15 which were separated by only 14.5 km.

At both pairs of stations (11 and 13; 14 and 15), markedly higher levels of inertial oscillations occur at the offshore location. The total standard deviation of the band passed currents at station 13 is 47% larger than that at station 11; the corresponding difference between station 14 and 15 is 39%. The cause of these differences is not clear. One possible explanation would be reduced winds at the inshore locations due to topographic effects, however, the inshore stations are still a considerable

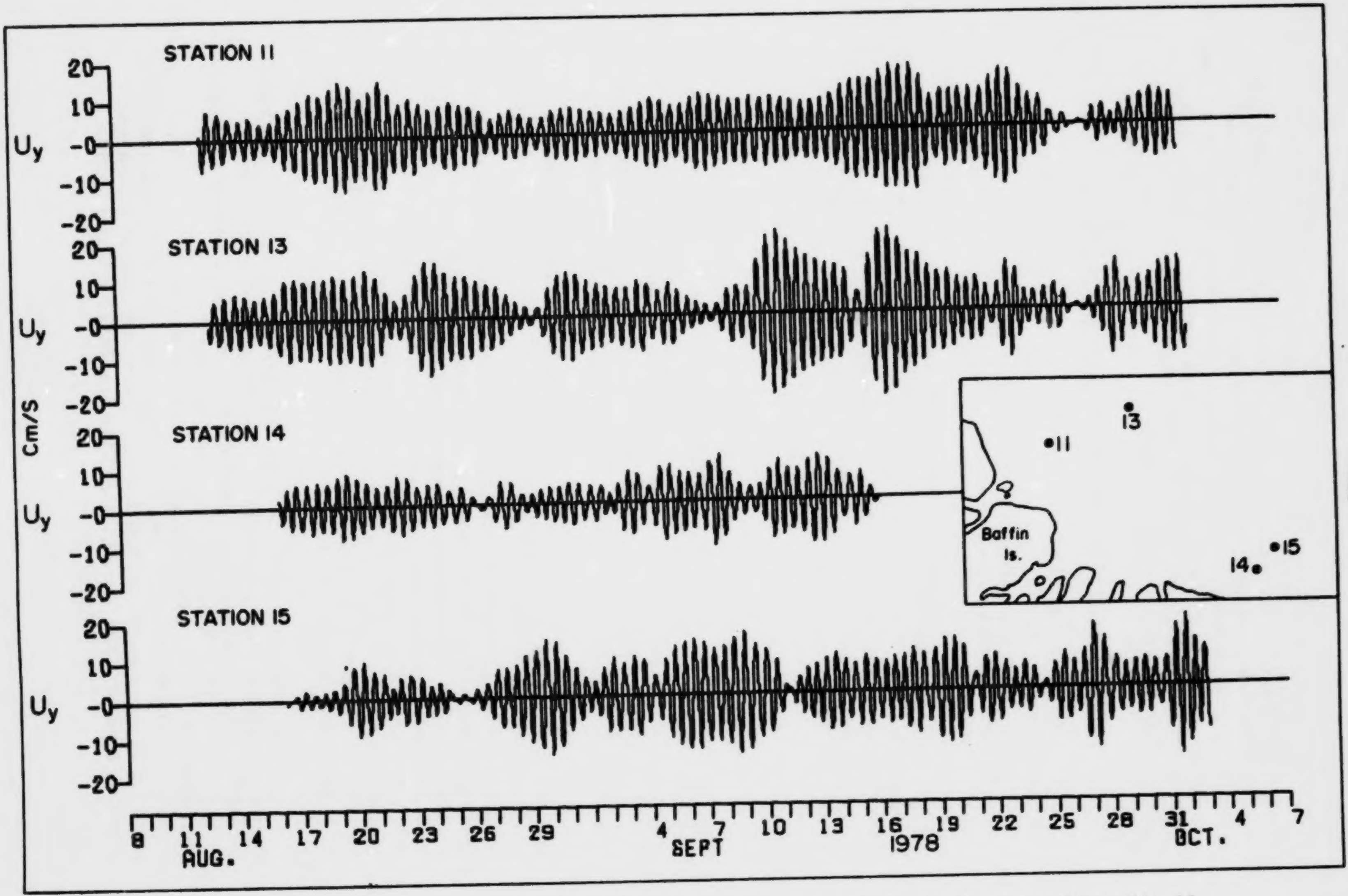


Figure 5.5-6: The semi-diurnal band passed northerly components at 35 m depth at stations 11, 13, 14 and 15 m in 1978.

distance from the coastline. Another possible cause would be a difference in the density structure. Because of the southward currents in the area combined with the less dense water from ice melt and land run-off in nearshore areas, the stratification is larger for inshore waters than for offshore waters. One consequence of this, is that the mixed layer depth is reduced at inshore stations: 8 ± 9 m as compared to 17 ± 9 m offshore (section 5.9). The decreased mixed layer depth and increased stratification inshore will tend to limit the inertial oscillations to the upper mixed layer because of the amount of work required to penetrate the more stratified waters below the mixed layer. This explanation suggests that reduced inertial oscillations at the nominal depth of 35 m of the upper current meter for inshore areas would occur at inshore sites as compared to offshore sites, in agreement with the comparisons for station pairs 11 and 13, and 14 and 15.

At station 13, inertial oscillations were found to be greatly reduced at 250 m depth as compared to 35 m depth. At stations 11 and 14, both located closer to shore in shallower water of depths 158 and 260 m, respectively, current meter data was obtained at depths of 125 m as well as 35 m. The amplitude of the inertial oscillations at 125 m as well as 35 m. The amplitude of the inertial oscillations at 125 m is markedly reduced from the levels observed at 35 m (see Figure 5.5-7), having a standard deviation of less than one-half that observed at 35 m. Because of the reduced levels, the semi-diurnal band passed easterly current component cannot be taken as a reliable indicator of inertial oscillations, being only 50% above the amplitude of the tidal currents in terms of standard deviation. This may explain, in part, the fact that no vertical coherence is visually apparent between the band-passed currents at 35 m and 125 m. The inertial oscillations at 125 m depth at stations 11 and 14 appear to be only marginally larger than those observed at 250 m depth at station 13. This comparison supports the suggestion that increased stratification of inshore locations limits the penetration of inertial oscillations as compared to more offshore locations. However, valid comparisons of inertial oscillation levels are difficult in view of the amount of contamination from tidal variations.

5.5.5 Inertial Oscillations off Eastern Devon Island

An analysis was made of inertial oscillations in the waters to the east of Devon Island, some 350 km north of the region discussed previously. The semi-diurnal tidal currents in this area are nearly twice as large, with the M_2 constituent being typically 5 to 7 cm/s in amplitude and oriented north-south. In other respects, the regions are similar; in both regions considerable wind fetches are found for winds from north to south-east and the dominant currents flow to the south.

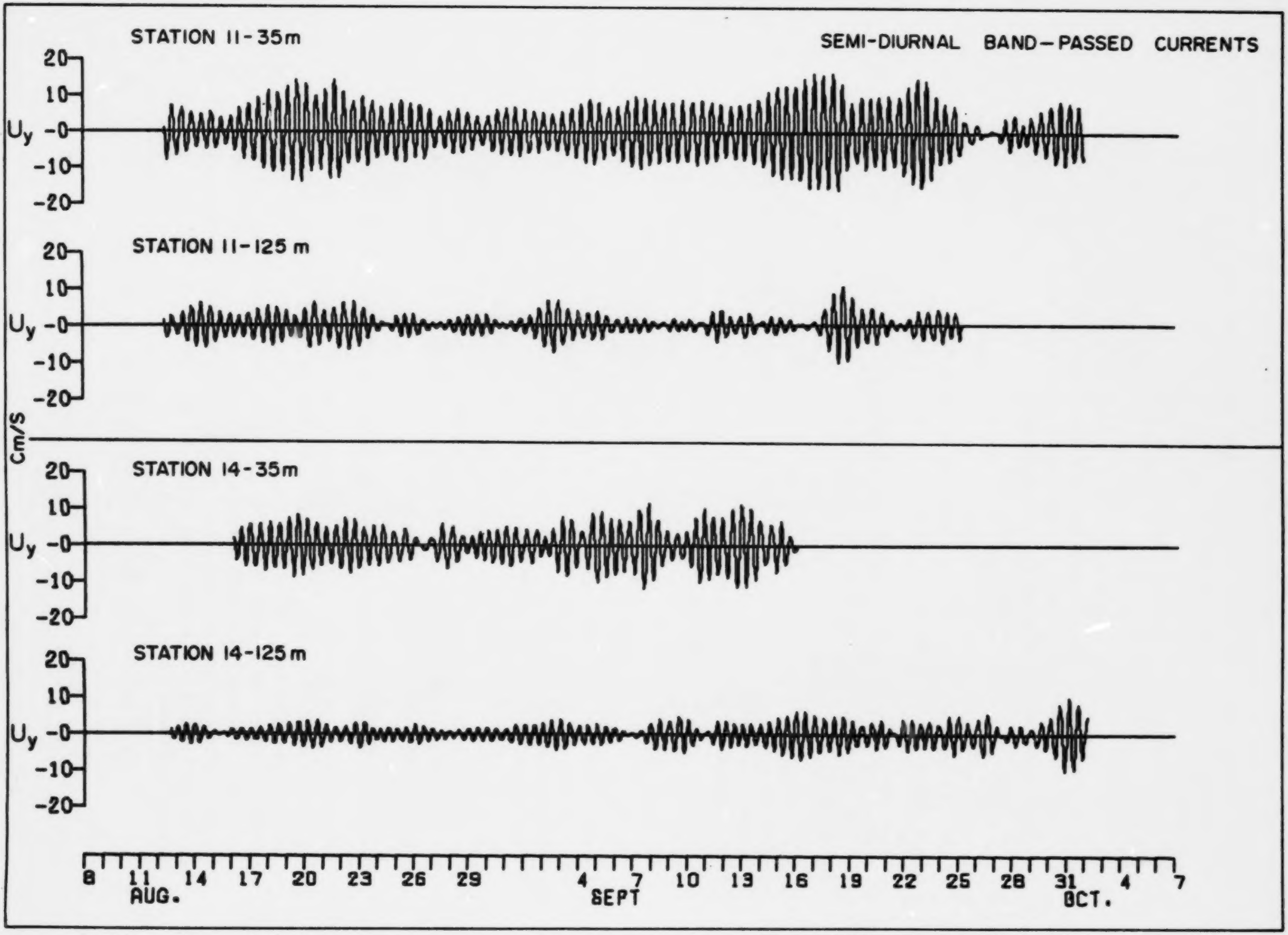


Figure 5.5-7: The semi-diurnal band passed northerly components at 35 and 125 m depths for stations 11 and 14 in 1978.

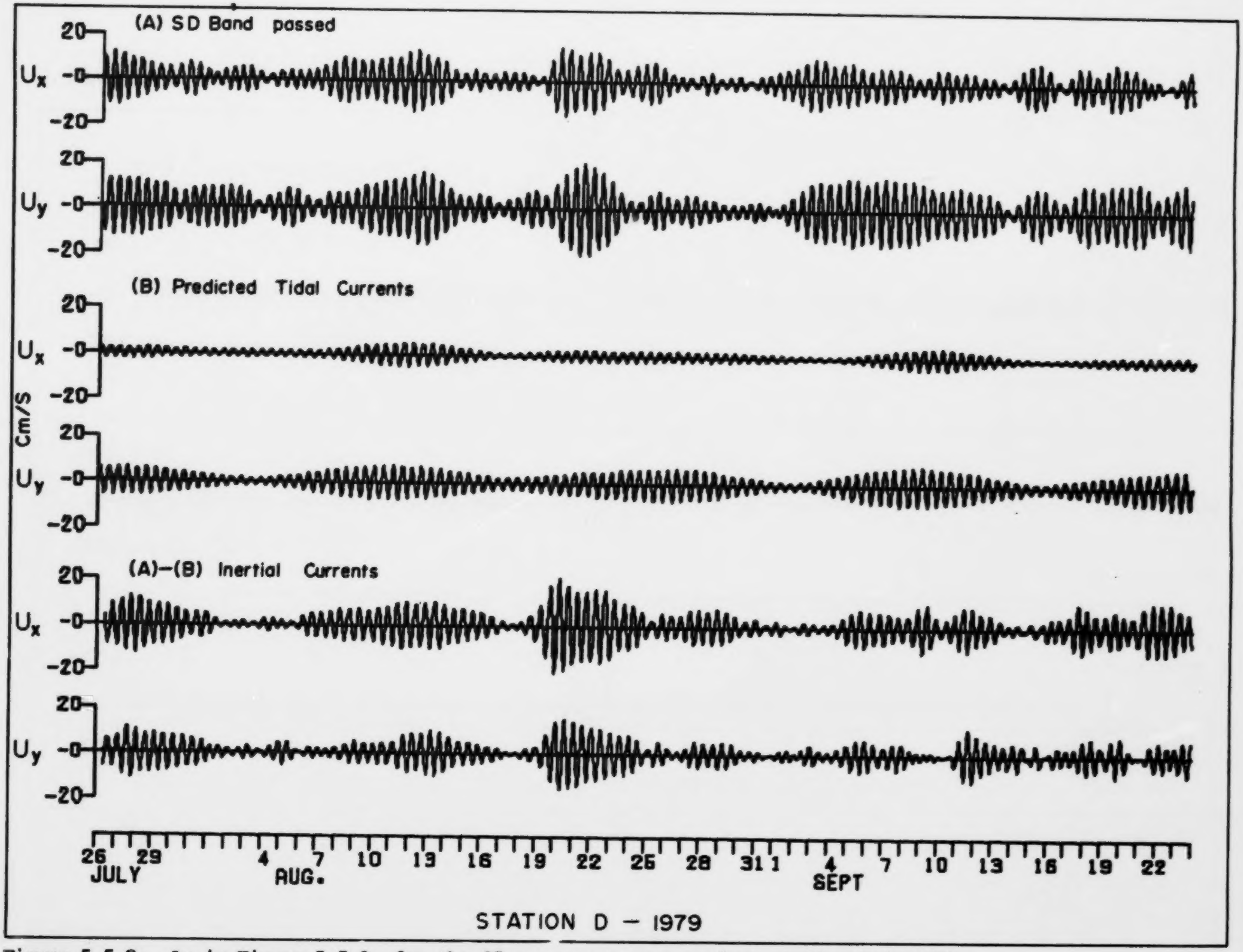


Figure 5.5-8: As in Figure 5.5-3, for the 35 m currents measured at station D in 1979.

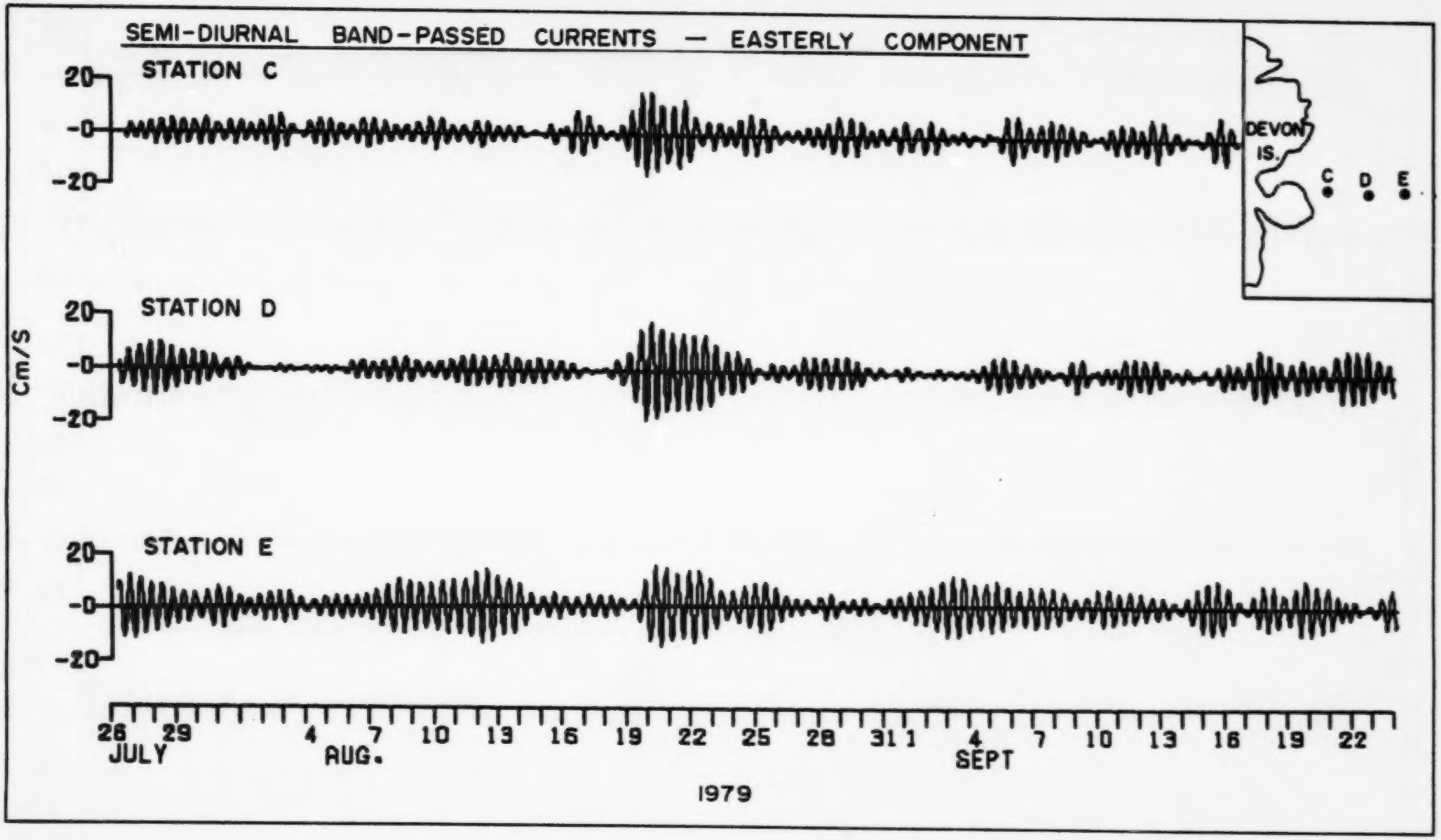


Figure 5.5-9: The semi-diurnal band passed easterly current components at stations C, D and E.

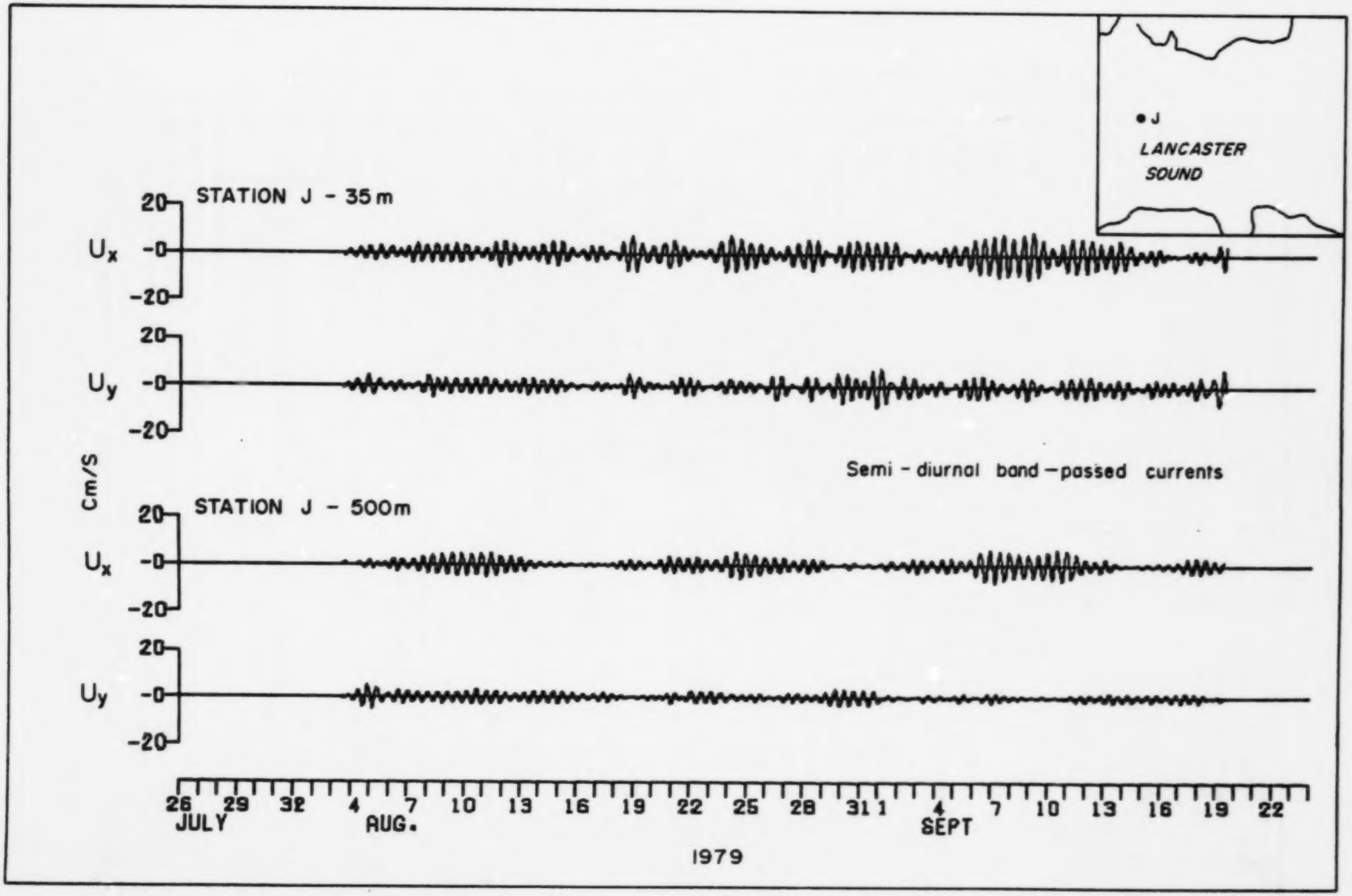


Figure 5.5-10: The semi-diurnal band passed current components at station J for depths of 35 m and 500 m.

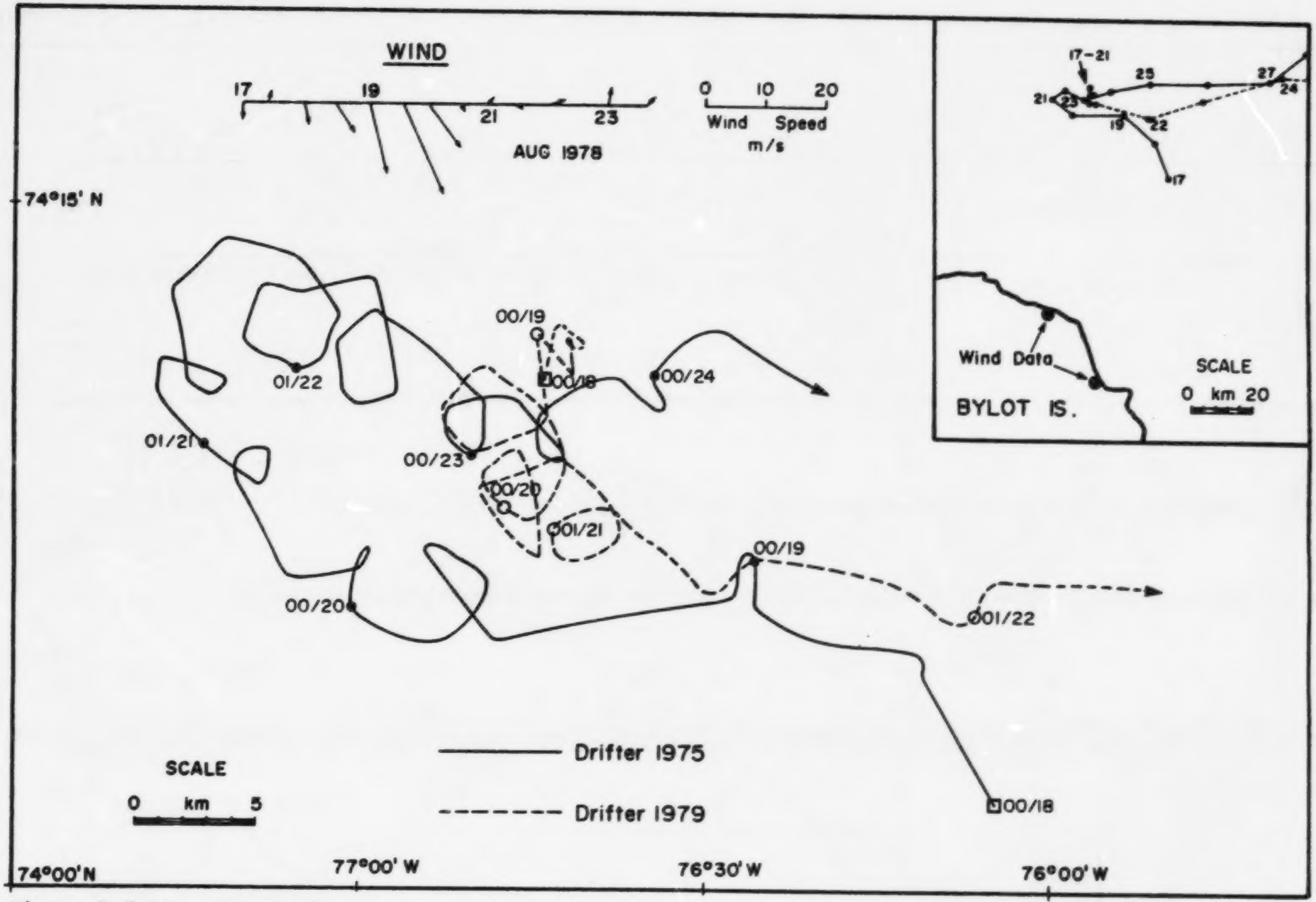

WIND
17
19
21
23
AUG 1978
0 10 20
Wind Speed
m/s
74°15' N
74°00'N
77°00' W
76°30' W
76°00' W
00/19
00/18
00/24
01/22
01/21
00/23
00/20
01/21
00/20
00/19
01/22
00/18
Drifter 1975
Drifter 1979
SCALE
0 km 5
17-21
25
27
24
21
23
19
22
17
Wind Data
BYLOT IS.
SCALE
0 km 20

Figure 5.5-11: The tracks of two satellite-tracked drifters during and immediately after a strong wind event on August 18-20, 1979. Inertial oscillations are evident in the tracks of both drifters.

At one location, station D, it was possible to remove the semi-dirunal tidal fluctuations by subtracting the predicted tidal currents as analysed from nearby (10 km separation) station 78-2, where current data was available for the ice-covered period of autumn 1978 to summer 1979 (see Figure 5.5-8). The inertial oscillations occur over periods of several days with typical amplitudes of 10 cm/s. The largest inertial oscillations at station D with peak amplitudes of 20 cm/s occurred from August 19-23, 1979 as a result of the passage of an intense cyclonic weather disturbance through Baffin Bay.

In Figure 5.5-9, the easterly component of the band-passed semi-diurnal currents is displayed for stations C, D and E, all occupied in the summer of 1979. Because the semi-diurnal tidal currents are primarily north-south oscillations, the easterly current components are largely free of tidal variations. The large inertial oscillations which occured on August 19-23 at all three stations constitute the largest dominant event of the season. However, aside from this common feature, one is struck more by differences than by similarities in the timing of inertial activity. On average, the activity of the inertial oscillations increases with distance from shore: the standard deviation of the band-passed easterly component increases from 3.8 cm/s (station C) to 4.2 cm/s (D) to 5.1 cm/s (E). This difference may result from the reduced exposure to winds at locations near the mountainous Devon Island coastline. An alternative explanation of the reduction could be due to the increased stratification of the inshore waters, as discussed previously.

The magnitude of the inertial oscillations observed in 1979, to the east of Devon Island, appears to be lower than that observed east of Baffin Island in 1978. This does not necessarily imply that the amplitude is significantly different between the two areas since the winds may have differed significantly between the two years. Evidence for this latter possibility is provided by the currents at two locations east of Baffin Island which were separated by only 3 km: station 15 occupied in the summer of 1978 and station R occupied in the summer of 1979. The level of the inertial oscillations as indicated by the semi-diurnal variations in the northerly component were significantly lower in 1979 with a standard deviation of 3.5 cm/s as compared to 6.3 cm/s in 1978 for a similar period of measurements.

5.5.6 Inertial Oscillations in Eastern Lancaster Sound

The SD band-passed time series computed from the 35 m current meter dta at station J is presented in Figure 5.5-10. Because the local M_2 tidal currents are aligned along the east-west axis of Lancaster Sound, the northerly current component provides the best representation of inertial oscillations. At this location, the magnitude of the inertial oscillations is strikingly low, in comparison with the magnitudes measured in Baffin Bay, with a typical amplitude of 4 cm/s and a maximum value of 11 cm/s.

5.5.7 Inertial Oscillations as Measured by Near-Surface Drifter Tracks

Inertial oscillations, being primarily forced by surface winds, are present at the surface as well as at depths through out the upper portion of the ocean. To examine inertial oscillations nearer the surface than subsurface current meter data permits, consider the tracks of two satellite-tracked drifters during the cyclonic weather disturbance of August 19-20 (see Figure 5.5-11). Prior to the wind event, one drifter (1975) was drifting to the northwest at approximately 15 cm/s while the other drifter (1979) separated by les than 15 km from the first, was moving very slowly with no apparent net motion. The winds began to increase, no response was apparent on the first day (August 18) when northerly to northwesterly winds of 5 m/s were blowing. The winds continued to increase and peaked on August 19 at speeds of 17 m/s. On this day, inertial oscillations were identifiable in the tracks of both drifters. Early on August 20, the winds declined rapidly and by mid-day they were weak and variable, a condition which persisted for the next 5 days. The inertial oscillations, once they began on August 19, continued to be apparent in the tracks of drifter 1975 and 1979 until August 23 and August 21, respectively. The circular pathlines of the drifters measured 3 to 5 km in diameter, corresponding to oscillatory speeds of 18 to 25 cm/s. Simultaneous measurements of the inertial oscillations were obtained at current meter station N located about 50 km to the southwest. Here, the inertial oscillations had peak speeds of approximately 15 cm/s and persisted with reduced magnitudes until August 23.

In addition to the inertial oscillations, another possible response to the wind event of August 19, was the eastward movement of both drifters which occurred following the storm. Drifter 1979 which had been moving slowly and sporadically earlier, began to drift eastwards at 20 cm/s while drifter 1975 reversed its previous net drift and moved to the east at 10 cm/s. This eastward movement is somewhat at variance with the low- frequency drift expected from northwesterly winds; using simple theory this should be to the right of the wind direction: i.e., southerly rather than easterly. It may be that the net drift was not solely due to the local wind field but arose, in part, from a larger scale response to the overall wind pattern.

5.5.8 Summary

We have examined in some detail inertial oscillations as measured in the data of subsurface current meters and satellite-tracked drifters. These oscillations, having periods ranging from 12.1 to 12.6 hours in the study area, are at times considerably stronger than the local semi-diurnal tidal oscillations. Their typical amplitudes are 10 to 20 cm/s with speeds as large as 30 cm/s being observed. Inertial oscillations are clearly observed at depths of 4 to 11 m from drifter data and at 35 m from current meter records; at depths of 250 m or more, they are so greatly reduced in amplitude as to be difficult to separate from the tidal variations with any confidence. Thus, large inertial oscillations appear to be confined to the Arctic water mass and concentrated in and immediately below the upper zone.

The properties of inertial oscillations observed over these depth ranges are very clearly related to the local surface wind. They occur intermittently at about the synoptic period of wind variations (3-10 days), and for particularly strong wind events such as that of August 19, 1979 inertial oscillations were generated at a wide range of locations. Once started, inertial oscillations typically persist for a period of 4 to 7 days.

Driving mechanicsm for the inertial oscillations other than generation by changes in the surface wind have been proposed. Hendershott (1965) has suggested that near latitudes where the inertial frequency matches that of semi-diurnal tidal oscillations, inertial oscillations can be generated by tidal resonance. For the strongest semi-diurnal tidal constituent M_2, the latitude at which the two frequencies agree is 74°28'. However, the data from current meter stations near this latitude (station 4 (74°30'), 10(74°31'), F(74°30') and G(74°26')) do not exhibit noticeably large amplitudes at the inertial frequency. From this, we conclude that the generation of inertial oscillations by resonance with tidal oscillations is a comparitively weak effect.

The amplitude of the inertial oscillations at 35 m depth in Baffin Bay increased with distance from shore for locations off both the east coasts of Devon and Baffin Islands. This difference may result from a possible reduction in the strength of the local winds at locations nearer the shoreline due to the sheltering effect of the mountain terrain of the nearby islands. However, information on the local winds is not sufficient to test this hypothesis. An alternative explanation is that the local stratification of the water column, being larger at inshore locations, may result in greater reductions in the amplitude of inertial oscillations at 35 m depth.

Little coherence, either vertical or horizontal, is visually apparent in the observed inertial oscillations at 35 m and 125 m depth over horizontal length scales as small as 15 km. This result is in general agreement with the findings of others (Munk and Phillips, 1968; Webster, 1968). Recently, Pollard (1980) found that the horizontal coherence scale of inertial oscillations varies significantly with depth in the upper oceanic layer. From current meter data at three locations in the vicinity of 39°10'N, 70W, separated by 50 to 70 km, he determined that inertial oscillations were highly coherent among the measurement sites at 12 m depth and less so at 32 m depth. However, at 52 m and 72 m no coherence was evident. For the purposes of predicting the oscillations, Pollard concluded that "the generation of inertial oscillations is so sensitive to variations in the wind that they cannot be predicted accurately in the absence of local wind records".

This preliminary analysis of inertial oscillations suggests that they may be of some importance in western Baffin Bay. Further analysis requires better data on the local winds along with more refined analytical techniques. One approach would be to apply recently developed numerical models (e.g., Pollard et al., 1973) to the sites of the 1978 and 1979 current meter measurements.

5.6 Nearshore Circulation

5.6.1 Introduction

Between the major offshore currents and the coastline is the nearshore zone. Here, the circulation can exhibit complex spatial patterns and a wide range of temporal variations due to a variety of forcing mechanisms including lateral boundary layer processes associated with strong offshore flows, local wind effects, enhanced freshwater input from land runoff and local ice melt, and large bathymetric gradients. In this section, examples of nearshore circulation features will be presented and analysed in view of some of these forcing mechanisms.

In the summer of 1979, Arcitc Sciences Ltd. carried out studies of the nearshore circulation at three sites: Cape Warrender, Cape Fanshawe and Cape Hay. The results from these three local-area studies are presented and used as examples for the discussion of some of the important features of nearshore circulation and their possible driving mechanisms.

The width of the nearshore zone is expected to vary according to the local forcing conditions. For the three nearshore areas studied in the summer of 1979, a width of about 10 km appeared to be appropriate.

5.6.2 Methods

The main purpose of the nearshore oceanographic studies was to gain an understanding of the surface circulation in these areas in order to provide insight into the movement of spilled oil. To simulate oil spill movements, oil spill followers (OSF) were tracked from inflatable boats. The oil spill followers consisted of several nylon-covered hoops joined together to form clusters; each cluster contained a small radio transmitter used to locate them from a small inflatable boat. Profiles of conductivity and temperature were also measured, as were wind data and some profiles of currents. Satellite tracked drogued drifters, deployed as part of the main offshore survey, helped provide the link necessary to relate observed nearshore features to the overall offshore dynamics. For more detail on the methods used, refer to Birch (1980a).

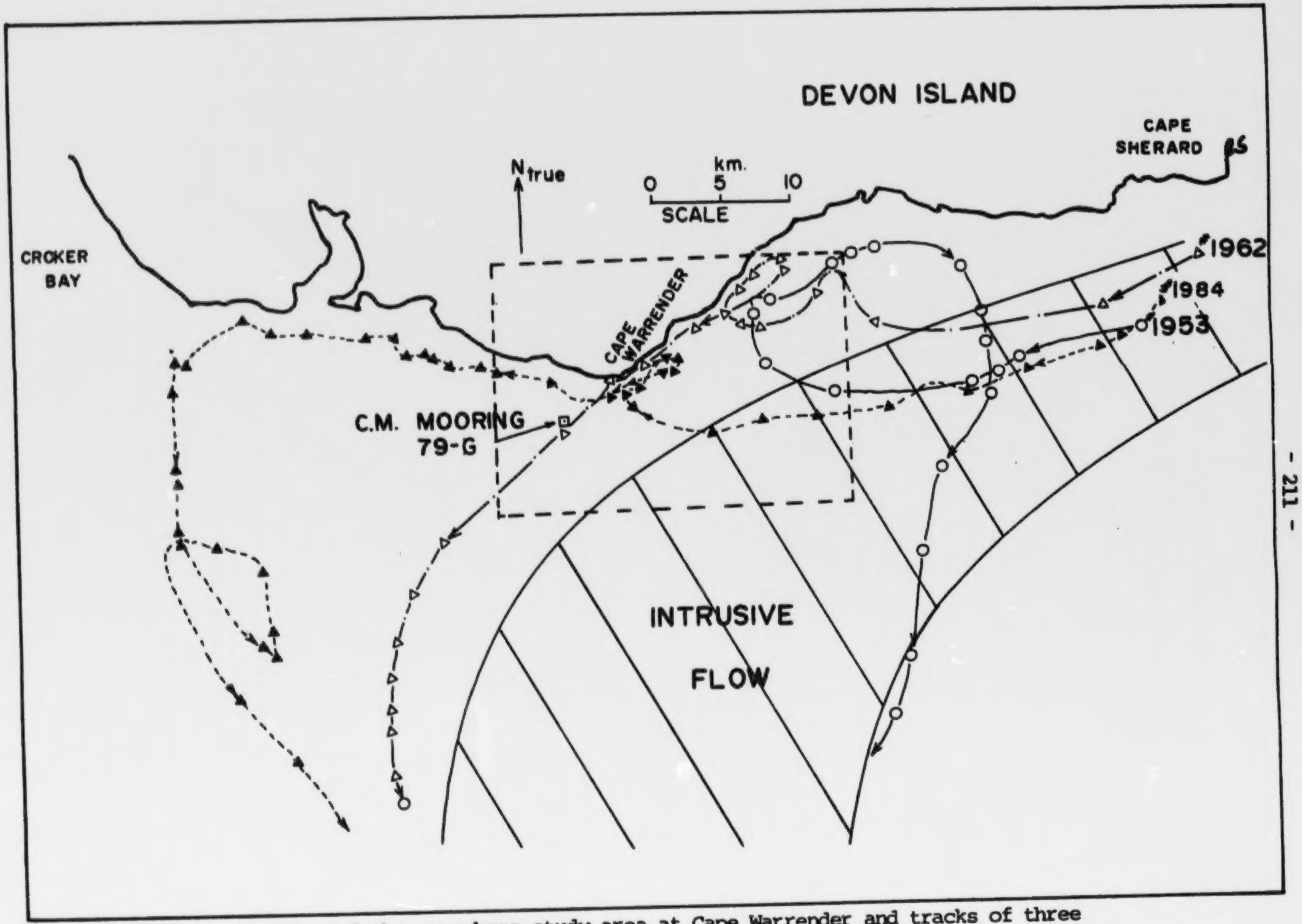

DEVON ISLAND
CAPE SHERARD
CROKER BAY
N true
0 5 10
km.
SCALE
CAPE WARRENDER
C.M. MOORING 79-G
1962
1984
1953
INTRUSIVE FLOW

Figure 5.6.3-1: Location of the nearshore study area at Cape Warrender and tracks of three drifters which left the usual pathway of the intrusive current.

5.6.3 Cape Warrender Nearshore Zone

Cape Warrender is on the north side of Lancaster Sound in the area (Figure 5.6.3-1) where the intrusive current breaks away from the Devon Island coastline and travels southward across the Sound. The position of the northern edge of the main intrusive current may vary somewhat during the summer of 1979 it was generally about 7 km southeast of Cape Warrender, with the main offshore currents flowing to the southwest at speeds of about 75 cm/sec (see section 5.2.3 for more detail on the intrusive current).

This nearshore area is a boundary zone between a strong offshore flow and the coast. Cape Warrender marks a separation point where the intrusive flow turns southward across the Sound. Between Capes Warrender and Sherard is a shallow coastal embayment which represents an area of relatively stagnant flow compared to that offshore. One would expect this nearshore area to be characterized by lateral velocity shears and entrainment of nearshore water into the main current. Such processes can produce eddy-like features as illustrated by the movements of drogued drifters numbers 1953, 1962 and 1984 (Figure 5e.6.3-1). These drifters left the main current and entered the nearshore zone. All three eventually rejoined the intrusive current but their movements in the nearshore zone illustrate the complicated surface circulation patterns that can occur.

Offshore of Cape Warrender the intrusive current turns south and moves across the Sound. Such a flow separation may result in eddy-like features in the area to the west of Cape Warrender. Figure 5.6.3-2 is a composite of ice movement on three successive days, June 20 - 22, 1974, based on satellite photos. The clockwise movement of the ice piece to the southwest of Cape Warrender illustrates the eddy-like flow that can occur. Study of the intrusive current in 1979 revealed an intermittent large-scale anticyclonic (clockwise) gyre just to the west of the cross-sound flow (see Fig. 5.2.3-11(c)) with the gyre extending north almost to Cape Warrender. The relevance of such offshore gyres to the nearshore area is that they may produce a southeasterly flow offshore to the west of Cape Warrender, while the offshore flow to the east of the Cape is generally southwesterly. The result would be a convergence of the two opposing flows, such as occurs downstream of a mid-channel obstruction. Such a flow pattern is suggested by some of the dynamic height data (see Figure 5.2.3.-4(c)). However, the southeasterly offshore flow to the west of Cape Warrender does not appear to be permanent. At times westerly flow is observed along the southern shore of Devon Island past Cape Warrender as in the case of the movement of drifter 1984 (Figure 5.6.3-1).

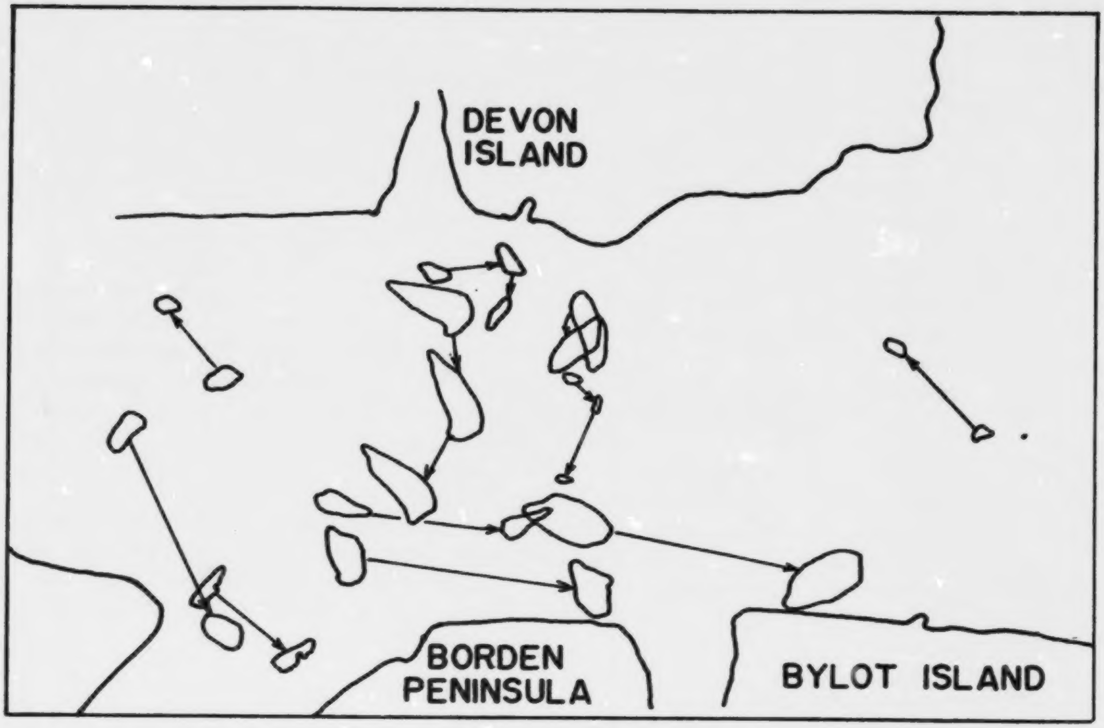

DEVON ISLAND
BORDEN PENINSULA
BYLOT ISLAND

Figure 5.6.3-2: A composite drawing of largefloe ice movements in Lancaster Sound, June 20-22, 1974, from satellite imagery.

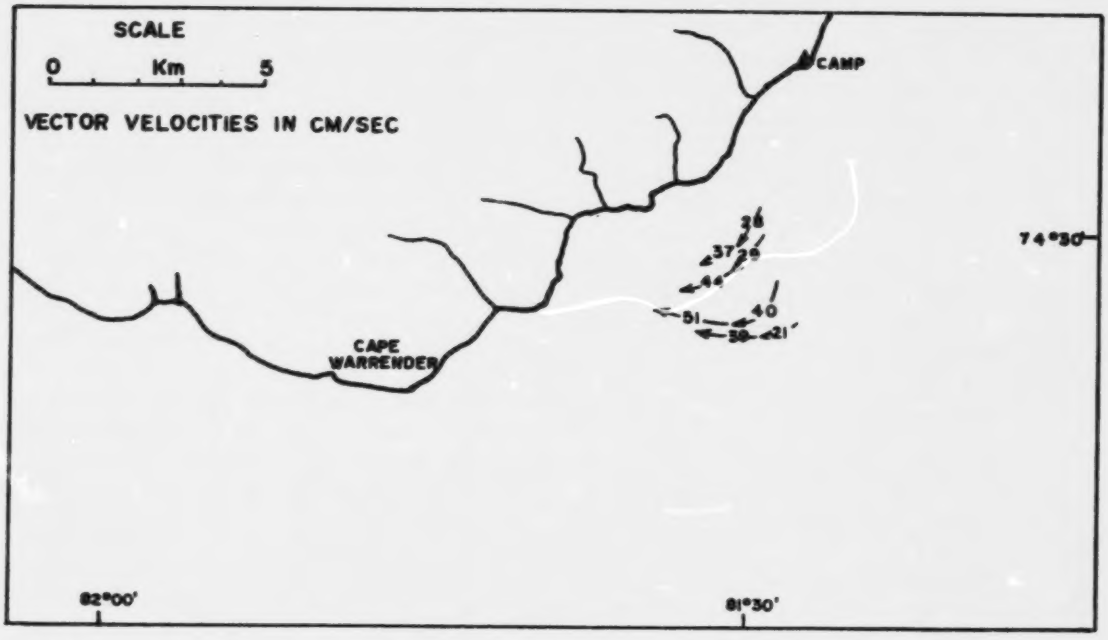

SCALE
0 Km 5
VECTOR VELOCITIES IN CM/SEC
CAMP
CAPE WARRENDER
26
37
29
44
40
51
30
21
74°30'
82°00'
81°30'

Figure 5.6.3-3: Movement of oil spill followers on August 1, 1979.

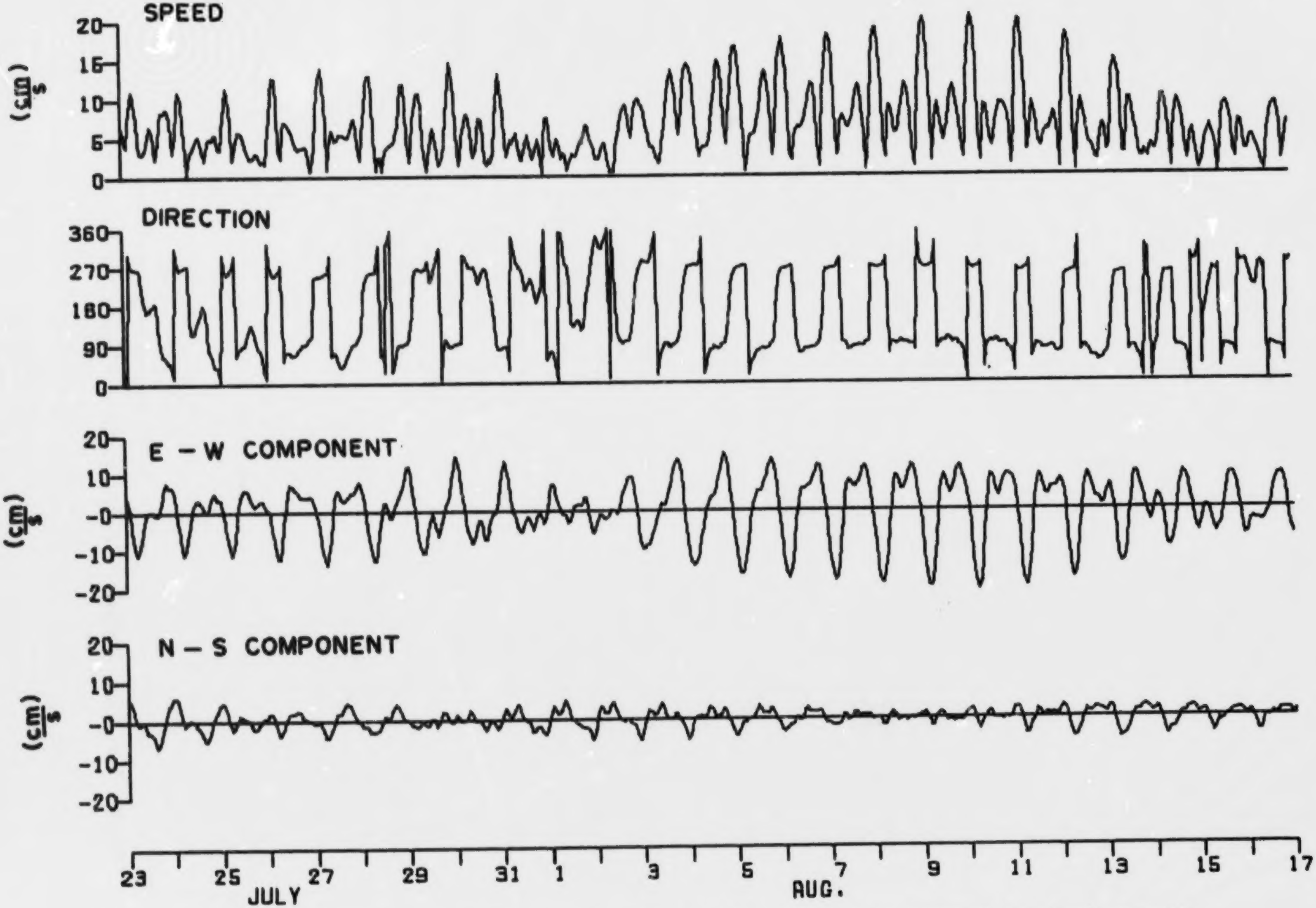


Figure 5.6.3-4: The predicted tidal currents for station G based on harmonic analysis results.

One of the important driving mechanisms of the nearshore circulation is the offshore flow. Unfortunately, during the period of nearshore studies at Cape Warrender, no drogued drifters were in the area at the time. Dynamic height plots for the period July 27 to August 10 (Figure 5.2.3-4(b)) suggest that some anticyclonic gyral flow was present along with the main southerly cross-sound flow. A current meter mooring (G) was located just southwest of Cape Warrender from July 23 to September 22, 1979; however the currents measured here are not a reliable indicator of the general offshore flow in this area. The currents at 42 m at mooring G are apparently not always representative of the surface flow in the area southwest of the Cape; on August 15 drifter 1984 moved west alongshore within 2.2 km of the mooring site, while the upper current meter at the mooring indicated an easterly flow.

In general, the oil spill follower data will have to be analysed without the benefit of knowing the general offshore circulation at the time. The approach will be to estimate the wind and tidal components of the observed trajectories, and remove these contributions, realizing trajectories that represent the residual flow.

Wind Forcing

The surface winds at the campsite, located 12 km northeast of Cape Warrender, were usually very different from those encounted over the water. Therefore all wind estimates used here will be based on observations from the boat tracking the oil spill followers.

According to a commonly used approximation, oil in the surface layer will move at roughtly 3% of the wind speed in the absence of any currents not due to the local surface winds; the direction of movement may be deflected to the right of the wind due to the Coriolis force. Figure 5.6.3-3 illustrates the effect of wind on the movement of the surface drifters (OSF's). From 0000 hr to 0130 hr on August 1, the wind was calm and the oil spill followers moved alongshore to the southwest at about 30 cm/sec. At about 0130 the wind strengthened to 7 - 8 m/sec from the east and the effect on the drifter motion was almost immediate, with the average speed of the drifters increasing to 43 cm/s and the drifters turning more to the west. The change in the drifter velocities is clearly due to the change in the surface wind. However, the increase in velocity is less than anticipated from the 3% rule (average increase of 13 cm/s as compared to the expected 23 cm/s). As well, there were significant differences in the response of individual drifters with speed increases varying from 9 to 18 cm/s. The discrepancies between the change in the drifters' motions and the 3% wind rule illustrate the inherent difficulties in applying simple parameterizations to complex phenomena such as wind-generated surface circulation.

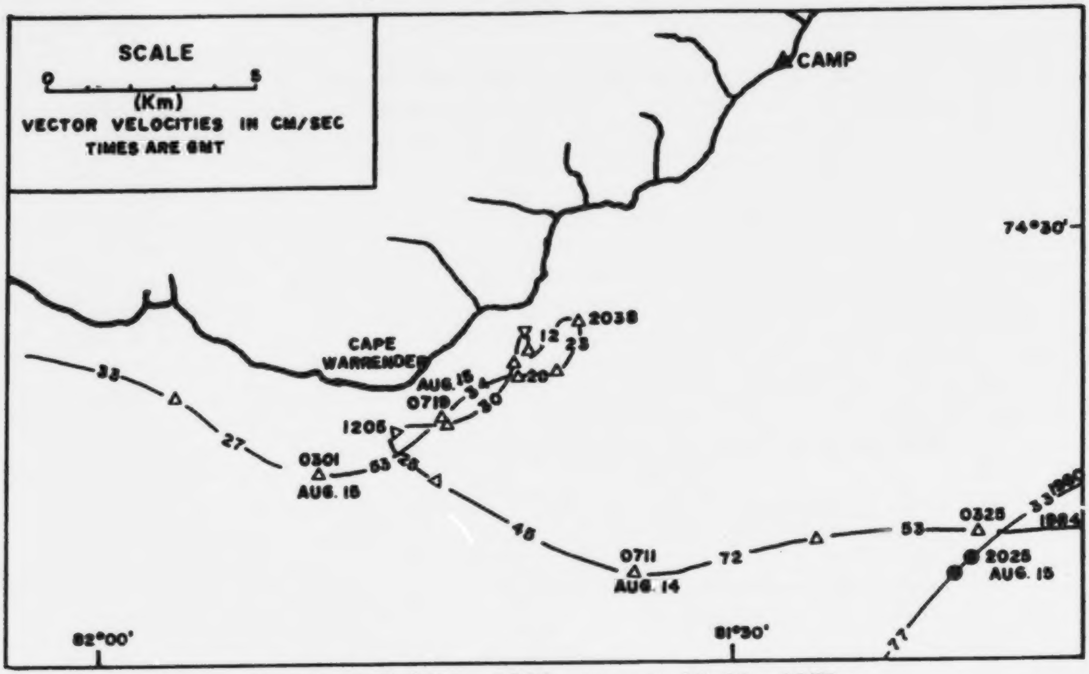

SCALE
0
5
(Km)
VECTOR VELOCITIES IN CM/SEC
TIMES ARE GMT
CAMP
74°30'
CAPE WARRENDER
2038
12
23
20
AUG. 15
0719
34
30
1205
33
27
0301
AUG. 15
53
28
48
0711
AUG. 14
72
53
0325
33
1980
1984
2025
AUG. 15
77
82°00'
81°30'

Figure 5.6.3-5: Track of drifter 1984, August 13-16, 1979.

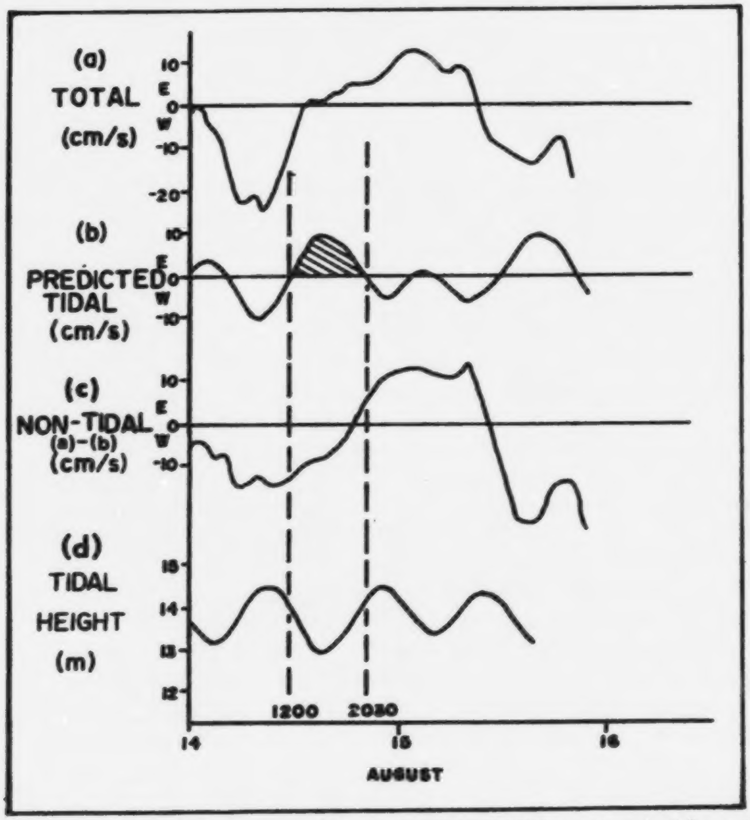


Figure 5.6.3-6: For 42 cm current data at station G, (a) the east-west component, (b) predicted east-west tidal component, (c) difference between (a) and (b): the non-tidal variations and (d) the predicted tidal height based on water level gauge data at Johnson Bay.

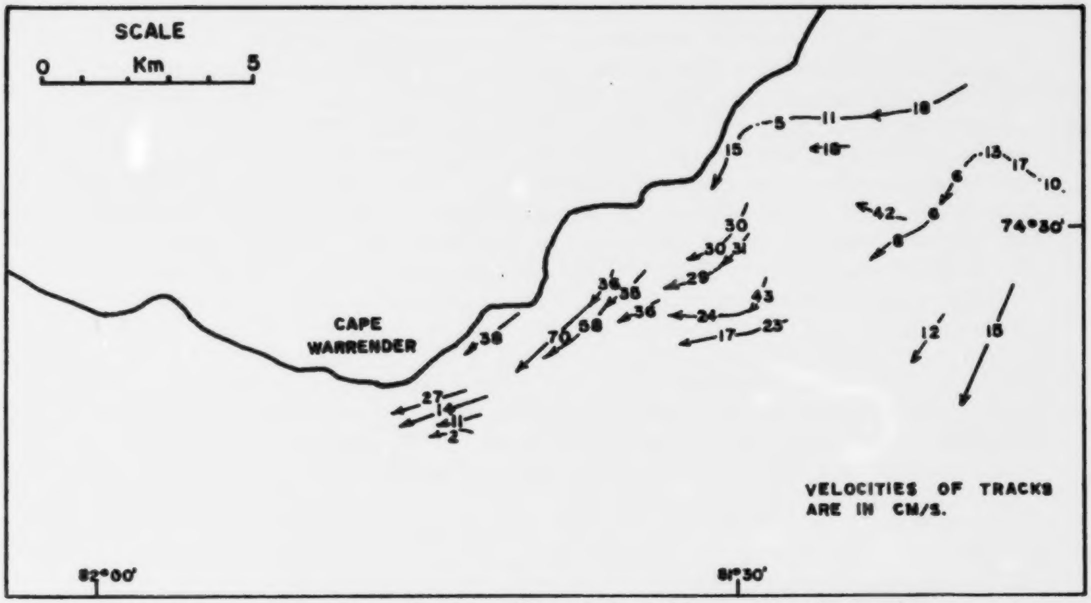

SCALE
0 Km 5
CAPE WARRENDER
5
11
18
15
18
13
17
10
6
6
8
42
74°30'
30
30
31
29
34
38
36
43
24
17
23
38
70
58
12
15
27
14
11
2
VELOCITIES OF TRACKS ARE IN CM/S.
82°00'
81°30'

Figure 5.6.3-7: Composite of all oil-spill follower trajectories, July 25 to August 6, 1979 following removal of effects of wind and tidal currents.

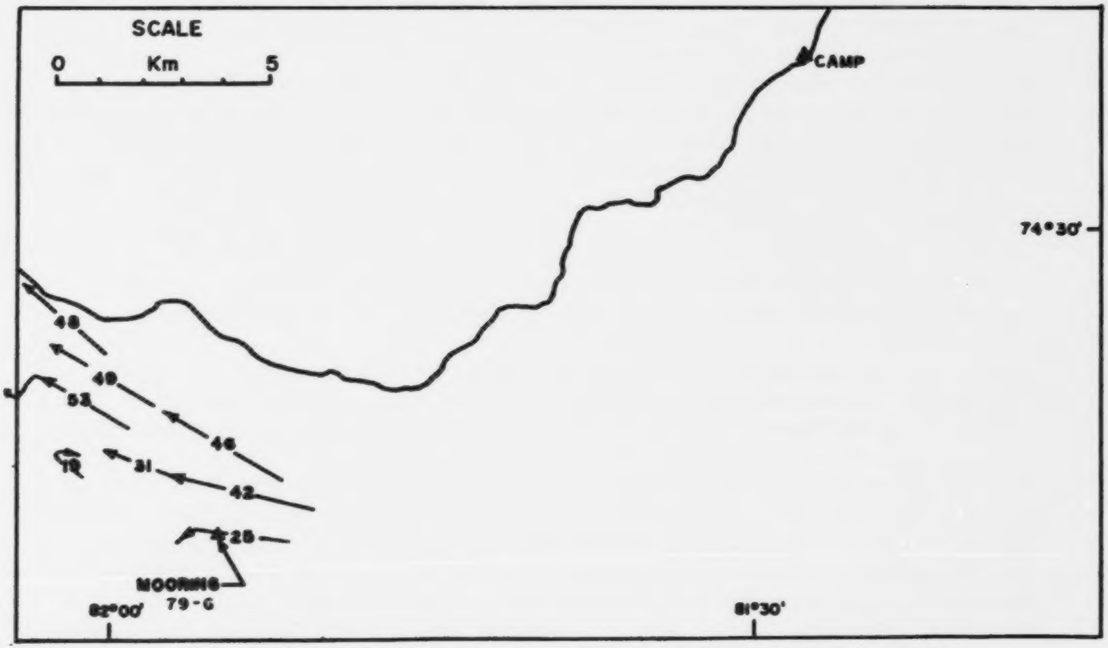

SCALE
0 Km 5
CAMP
74°30'
48
49
53
46
19
31
42
25
MOORING 79-G
82°00'
81°30'

Figure 5.6.3-8: Trajectories of oil-spill followers on August 14, 1979. Velocities labelled on tracks are in cm/s.

Tidal Forcing

The tides in this area are mixed, mainly semi-diurnal. Typical tidal ranges are 1.7 m, increasing to 2.5 m during spring tides (based on 1978-1979 Johnson Bay tidal record, Birch 1980(b)). A harmonic analysis of the tidal currents from station G, 42 m, using the program of Foreman (1978) shows that tidal currents are orientated east-west, reaching peak speeds of 20 cm/s (see Figure 5.6.3-4). In contrast to the tidal height variations, the largest variations of the tidal currents are at diurnal rather than semi-diurnal frequencies. This difference in the character of the tidal heights and currents may result from internal tides (see Section 5.4).

Drogued drifters which entered the nearshore zone exhibited motion which was apparently due to tidal forcing. As an example, consider the motion of drifter 1984 (Figure 5.6.3-5). Early on August 14, it left the main intrusive flow and moved towards Cape Warrender. At about 1200 hr, it was within 1 km of the Cape and switched direction to the northeast. From 1205 to 2038 hr, it moved northeast along shore; then at 2038 hr, it reversed its direction and headed southwest, eventually leaving the area. Figure 5.6.3-6 shows (a) the E-W component of the total flow at 42 m, mooring G, (b) the E-W component of the predicted tidal current at the same mooring, and (c) the difference of the two which should be the non-tidal E-W flow component and, (d) the tidal elevation. The period when 1984 moved northeast alongshore is shaded in and corresponds to the period of easterly tidal flow. Tidal currents were predicted to reach speeds of 10 cm/sec to the east during this period. It appears that during the period 1200 - 2030, the drifter responded to the easterly tidal flow. The reversal in direction of the drifter (at 2038 hr) occurred when the tidal flow reversed; even though the total flow at mooring G was still easterly, the drifter appeared to respond to the westerly tidal component. This gives further evidence that the non-tidal variations of subsurface currents at mooring G are not representative of non-tidal currents of the nearshore surface currents to the east of Cape Warrender.

The agreement between the tidal currents deduced from subsurface current mesurements at mooring G and the currents measured by drifter 1984 is limited to times of flow reversals; the peak speed of the easterly movement of drifter 1984 (30 cm/s) is considerably larger than the peak predicted easterly tidal flow from mooring G (10 cm/s). This difference in the amplitude of the tidal currents could result from the effect of internal tides. Evidence of the amplification of K_1 tidal currents in the nearshore zone has been presented for subsurface current measurement sites off Cape Crauford (Section 5.4.6) and for deeper measurement sites near Cape Hay (Section 5.4.5). Thus, the larger amplitudes of the movements of drifter 1984 could result from enhanced internal tides present in the Cape Warrender nearshore zone.

Surface Circulation

The surface circulation in the Cape Warrender nearshore zone, as measured by oil spill follower movement, is summarized in Figures 5.6.3-7 and 5.6.3-8, for the areas east and west of the Cape, respectively. For these figures, an attempt was made to remove the effect of the local wind by subtracting 3% of the local surface wind velocity vector. Similarly, the effect of the local tidal flow was removed by subtracting the tidal currents predicted from the harmonic analysis results of the current meter data at 42 m depth of mooring G. In view of the lack of quantitive agreement of the drifter velocities with either the 3% wind rule or the predicted tidal currents from the examples discussed above, these corrections are not expected to completely remove either of these effects. To completely remove these influences requires a much improved theoretical understanding of these complex phenomena than is currently available, particularly in the case of nearshore zones.

The the east of Cape Warrender (Figure 5.6.3-7), the deduced net flows are southwesterly with speeds ranging from 2 to 70 cm/s, and typical flow speeds of 20 cm/s. The nearshore surface currents are markedly reduced from the currents measured in the intrusive current (median speed of 73 cm/s) located further offshore.

To the west of Cape Warrender (Figure 5.6.3-8), the corrected surface velocities are based on measurements collected during only one day of observations (August 14). The net velocities were westerly to northwesterly, with speeds ranging from 19 to 53 cm/s. Subsurface currents measured at 42 m depth at station G were also westerly at this time; however, the net subsurface flow at station G was easterly to southeasterly over extended periods of time, suggesting that similar reversals in the net surface flow could occur to the west of Cape Warrender.

In view of the relatively low surface velocities measured in the nearshore zone as compared to the flow speeds observed in the adjacent offshore zone, and the directional variability of the net subsurface flows at mooring G, reversals from the overall pattern of westerly motion are expected in the Cape Warrender nearshore zone. These reversals could result from westerly winds, tidal currents enhanced due to internal tides and lateral boundary layer eddies shed from the strong offshore flows of the intrusive current, or various combinations of these driving mechanisms. Indeed, evidence of such reversals is provided by the tracks of drogued satellite-tracked drifters passing through the nearshore zone (Figure 5.6.3-1).

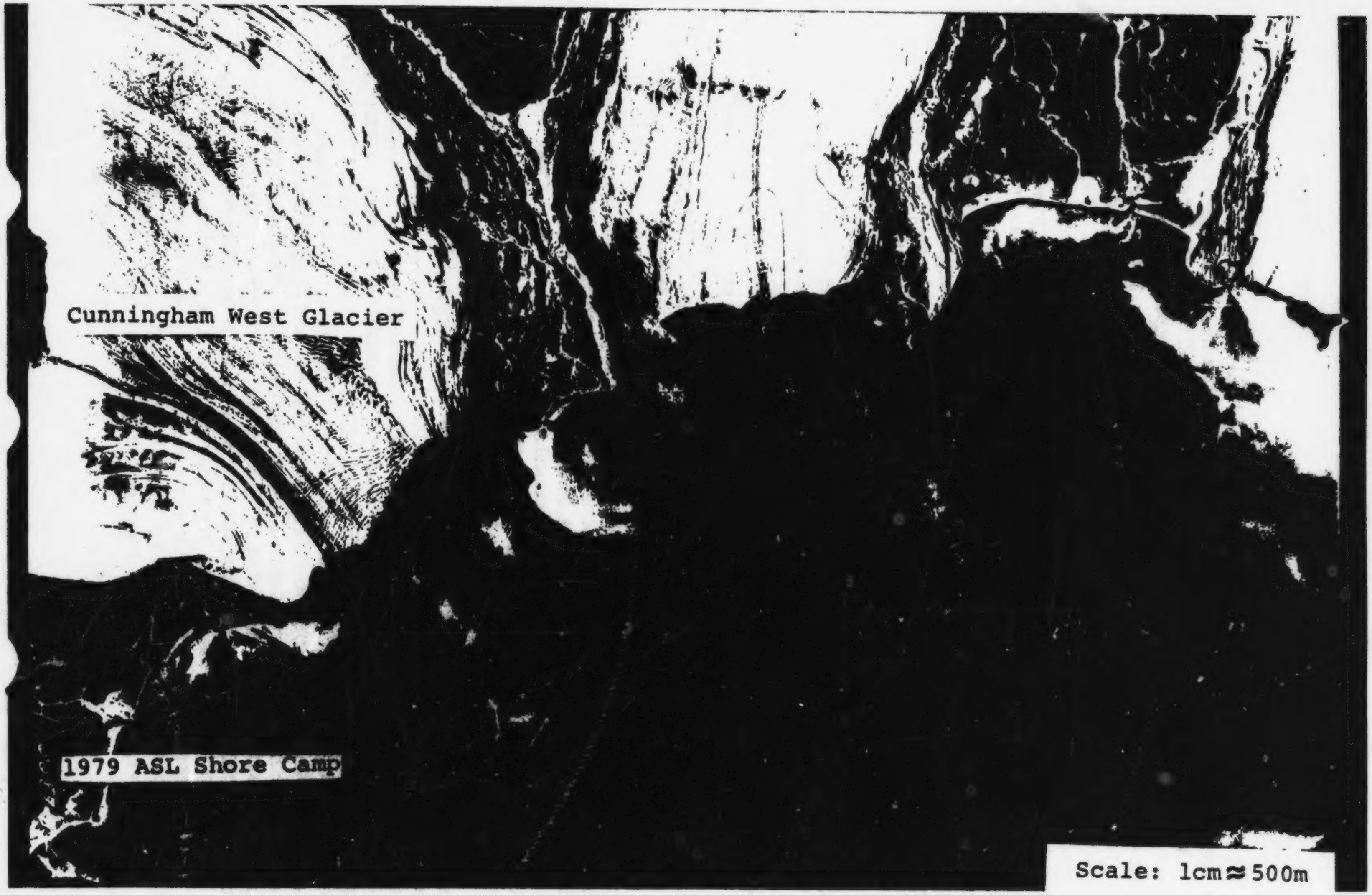

Cunningham West Glacier
1979 ASL Shore Camp
Scale: 1cm≈500m

Figure 5.6.3-9: Three arms of Cunningham Glacier, between Capes Warrender and Sherard. (1959 photo from 30,000', courtesy of National Air Photo Library, Ottawa).

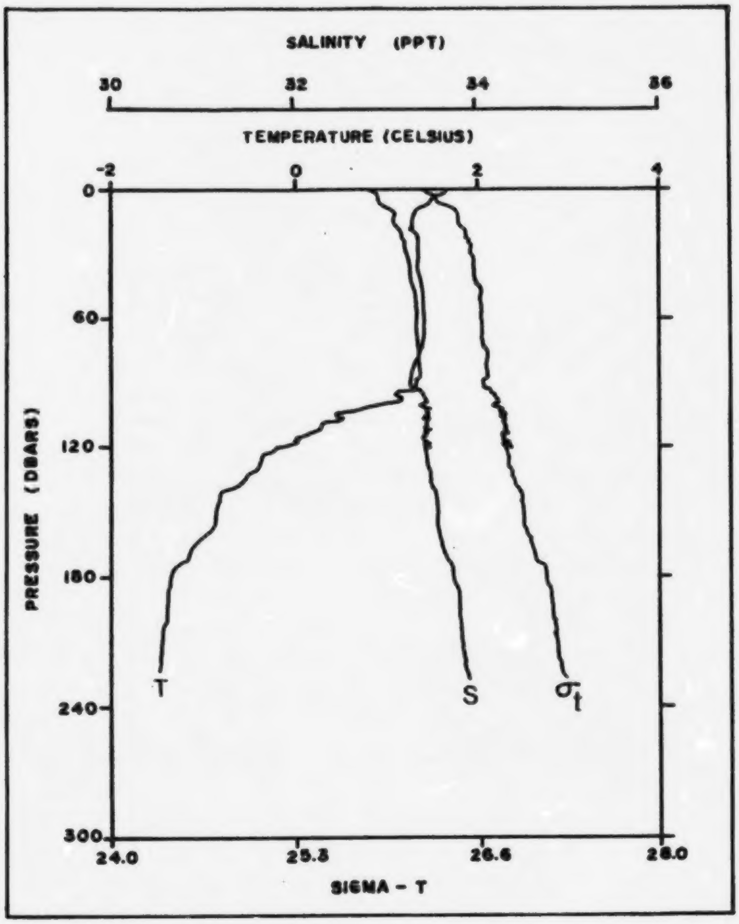


Figure 5.6.3-10: CTD profile at station 8 km east of Cape Warrender and 2 km from shore, August 7, 1979.

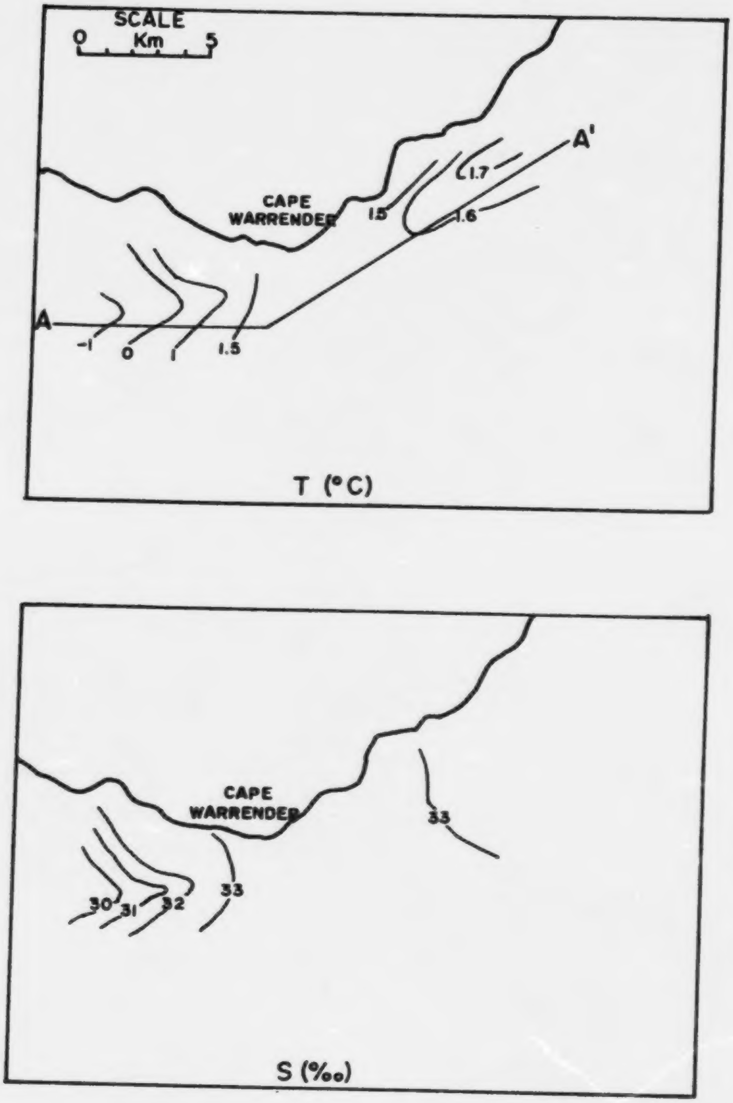

SCALE
0
Km
5
CAPE WARRENDER
A
A'
-1
0
1
1.5
1.5
1.7
1.6
T (°C)
CAPE WARRENDER
30
31
32
33
33
S (‰)

Figure 5.6.3-11: Surface temperature and salinity distribution off Cape Warrender, August 7-8, 1979.

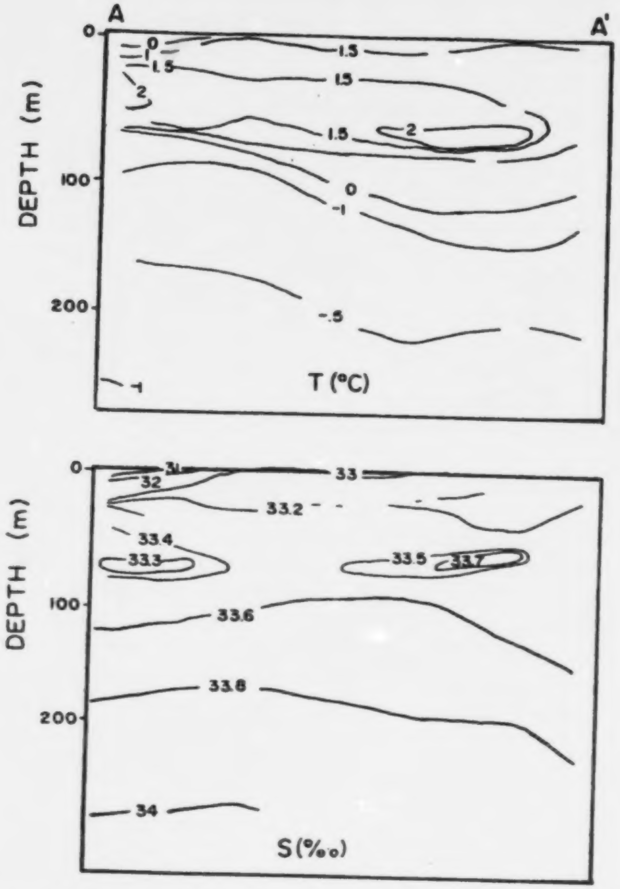


Figure 5.6.3-12: Vertical section of temperature and salinity through section A-A' shown in Figure 5.6.3-11.

Water Properties

Between Capes Warrender and Sherard is an embayment which in summer receives the runoff of meltwater from Cunningham Glacier. The meltwater is milky in colour due to glacial rock-flour. The aerial photo reproduced in Figure 5.6.3-9 shows the extend of this runoff during July 1959. The ripple-like patterns in the lower left are believed to be internal waves which propagate along the density interface between the thin surface layer of fresher water and the underlying Arctic Water. During the summer 1979 study, meltwater was often concentrated in a band about 1 km wide extending alongshore towards Cape Warrender.

Figure 5.6.3-10 shows the data from a CTD profile taken on August 7 at a station 8 km east of Cape Warrender and 2 km offshore. Down to depths of 70 to 100 m there is an upper variable layer, which is essentially Arctic Water that has been warmed by solar heating and modified by runoff. Below this is typical cold Arctic Water extending to a depth of about 240 m.

During the summer 1979 study, CTD profiles revealed a surface concentration of cold, fresh water to the southwest of Cape Warrender (see Figures 5.6.3-11 and 5.6.3-12). This cold, fresh layer extended to about 25 m depth, apparently too deep to result from local runoff alone. It may represent the northeast limit of Arctic Water originating further to the west in Lancaster Sound. Such features restrict the use of geostrophic calculations in this area because we do not know if these water masses are in geostrophic balance; also a reference level is difficult to establish, particularly since the currents at 250 m depth (station G) are significant and quite variable.

Summary

The surface circulation near Cape Warrender is a result of offshore dynamics, modified by local wind, tides, and bathymetry. All these factors must be considered for a complete understanding of the nearshore circulation.

During the summer of 1979, the surface nearshore flow to the east of the Cape was generally to the southwest, alongshore, at speeds of about 20 cm/sec. Reversals to the northeast were observed in drogued drifter trajectories and these were apparently due to a combination of lateral boundary layer eddies shed from the main intrusive current and relatively strong nearshore tidal flows. The observations of currents to the west of the Cape are more limited. Evidence from the oil spill follower and drogued drifter tracks, ice floe movements and subsurface current meter data, suggest that considerable variability in the net flow occurs with preference for alongshore motions to the northwest or southeast.

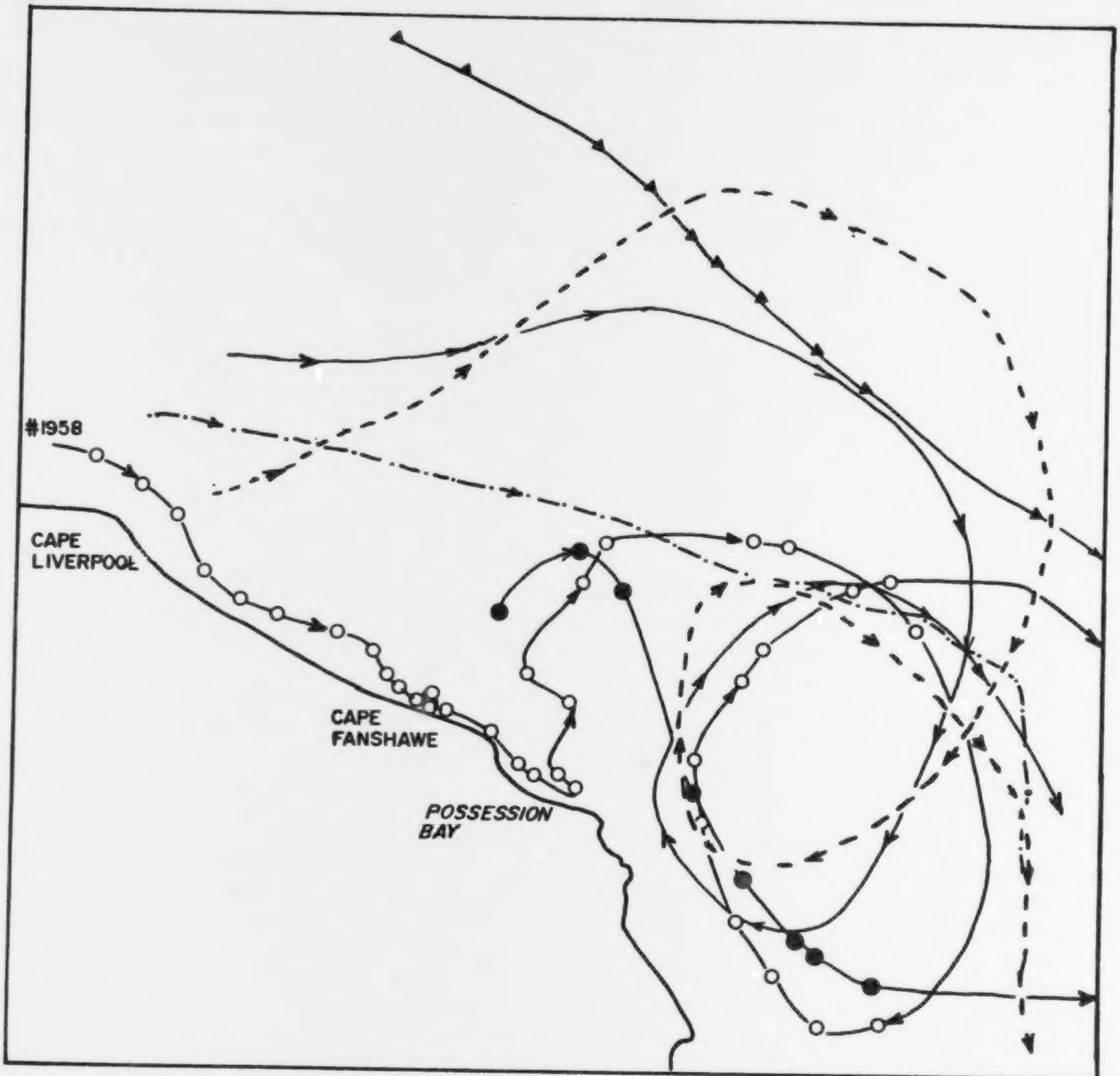

#1958
CAPE
LIVERPOOL
CAPE
FANSHAWE
POSSESSION
BAY

Figure 5.6.4-1: Trajectories of drogued drifters passing near Cape Fanshawe study area.

5.6.4 Cape Fanshawe Nearshore Zone

Cape Fanshawe is located on the northeast coast of Bylot Island (Figure 5.6.4-1). To the north of Cape Fanshawe, offshore of Cape Liverpool, the outflow from Lancaster Sound tends to move to the east, away from the coast. The flow continues east to a distance of about 40 - 50 km offshore and then turns southeast. Directly to the east of Cape Fanshawe, about 45 km offshore, is a region in which many anticyclonic (clockwise) eddies have been observed, both in 1978 and 1979 (see Section 5.2.5 for more detail). Thus, the Cape Fanshawe study area is bounded by a flow separation zone to the north and an eddy zone offshore to the east. Figure 5.6.4-1 shows portions of several drogued drifter trajectories which illustrate the offshore circulation features.

Bathymetry

Bathymetry data is scarce for this area. Soundings from hydrographic chart 7220 indicate depths of about 1000 meters, 7 km offshore. Within 1.5 km of Cape Fanshawe, depths of less than 40 m were measured during the summer of 1979.

Water Properties

It was not possible to obtain salinity data nearshore due to instrumentation problems. Aerial photos for earlier years (1948, 1958 and 1960) show that the Bathurst Bay region, to the south of Cape Fanshawe, receives large quantities of glacial runoff, particularly in July. In 1948, this runoff moved south alongshore. Maud Bight, to the northwest of Cape Fanshawe also contributes some runoff and this less saline water probably mixes with the outflow from Lancaster Sound.

Figure 5.6.4-2 shows a typical temperature profile (August 29, 1979) for the nearshore zone. It was taken 3 km offshore of Cape Fanshawe. An upper variable layer about 50 m thick overlies the colder Arctic Water. At the time of study, an on-offshore gradient in water temperatures was observed with the water nearer shore being colder than that offshore (see Figure 5.6.4-3). This temperature gradient was evident at all depths measured. Since variations of these low temperatures have little effect on density, the gradient does not necessarily represent a density gradient. During the study, the net surface flow was offshore; this may have produced a compensating onshore flow of deeper water resulting in an upwelling of the deeper, colder water in the nearshore zone.

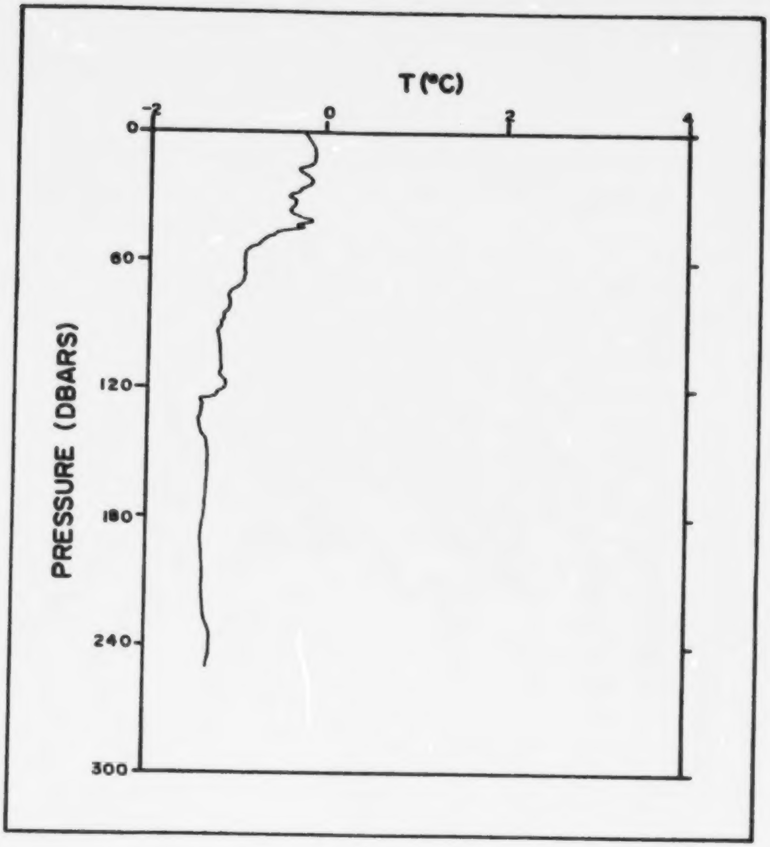


Figure 5.6.4-2: Temperature profile at station off Cape Fanshawe, August 29, 1979.

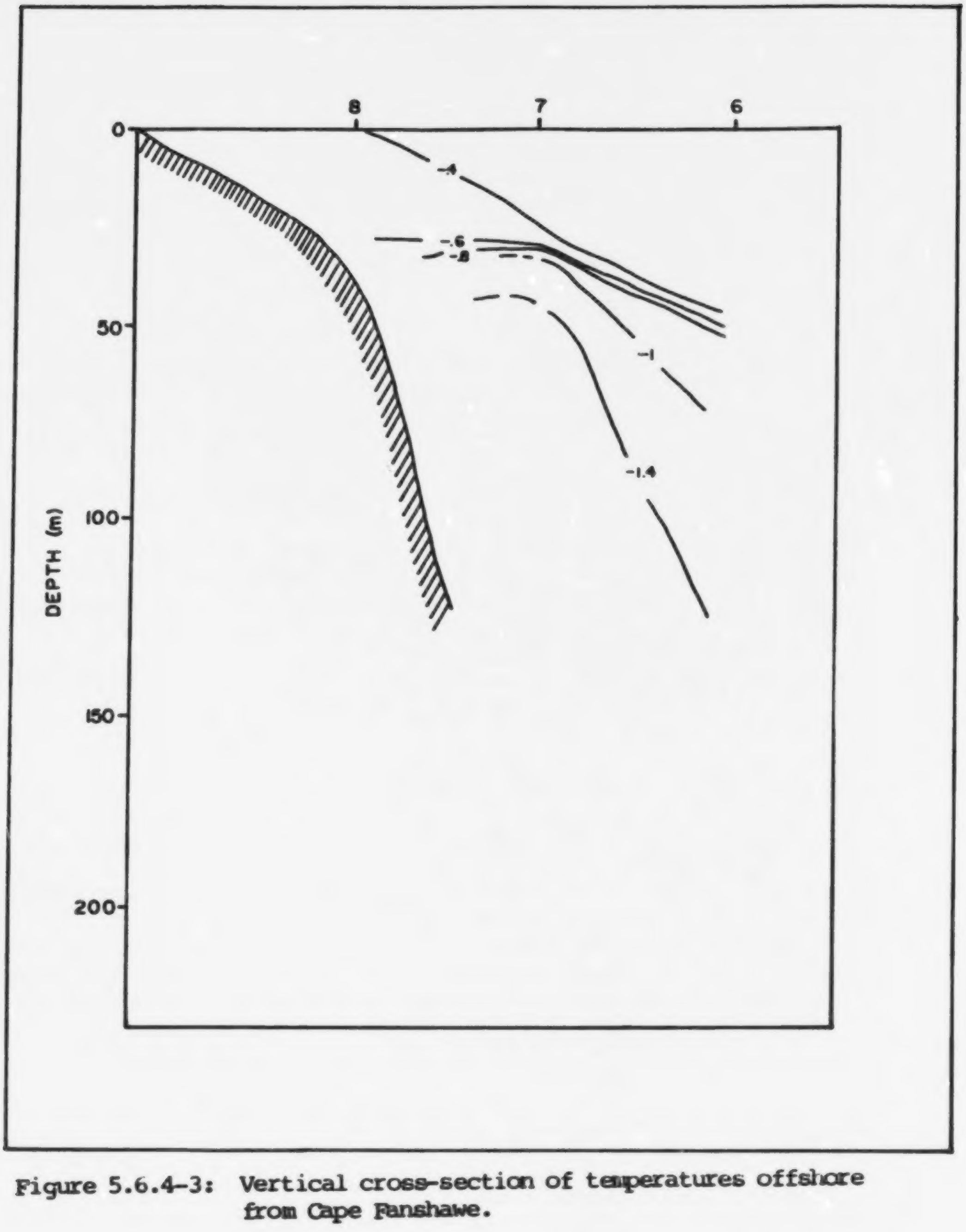


Figure 5.6.4-3: Vertical cross-section of temperatures offshore from Cape Fanshawe.

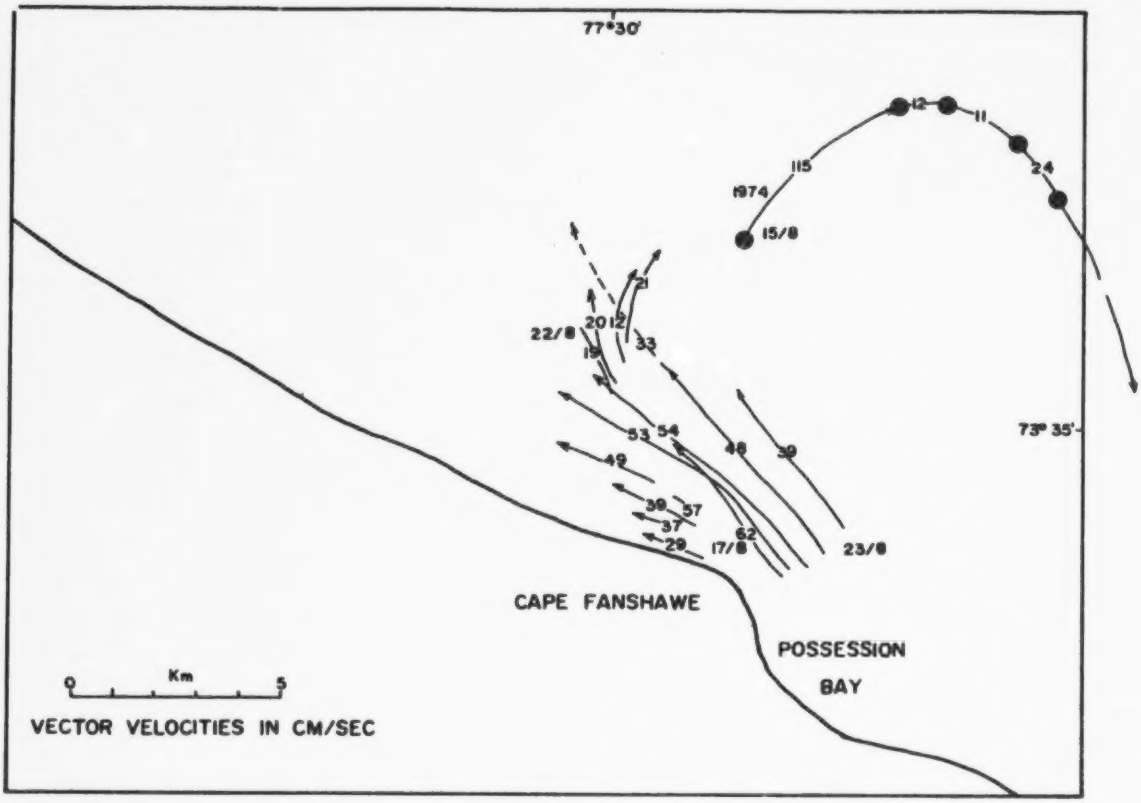

77°30'
12
11
115
1974
24
15/8
21
22/8
20
12
19
33
53
54
48
39
49
39
57
37
62
29
17/8
23/8
73° 35'
CAPE FANSHAWE
POSSESSION
BAY
0
Km
5
VECTOR VELOCITIES IN CM/SEC

Figure 5.6.4-4: Composite of oil spill follower tracks in Cape Fanshawe nearshore study area. Also shown is track of drogued drifter 1974.

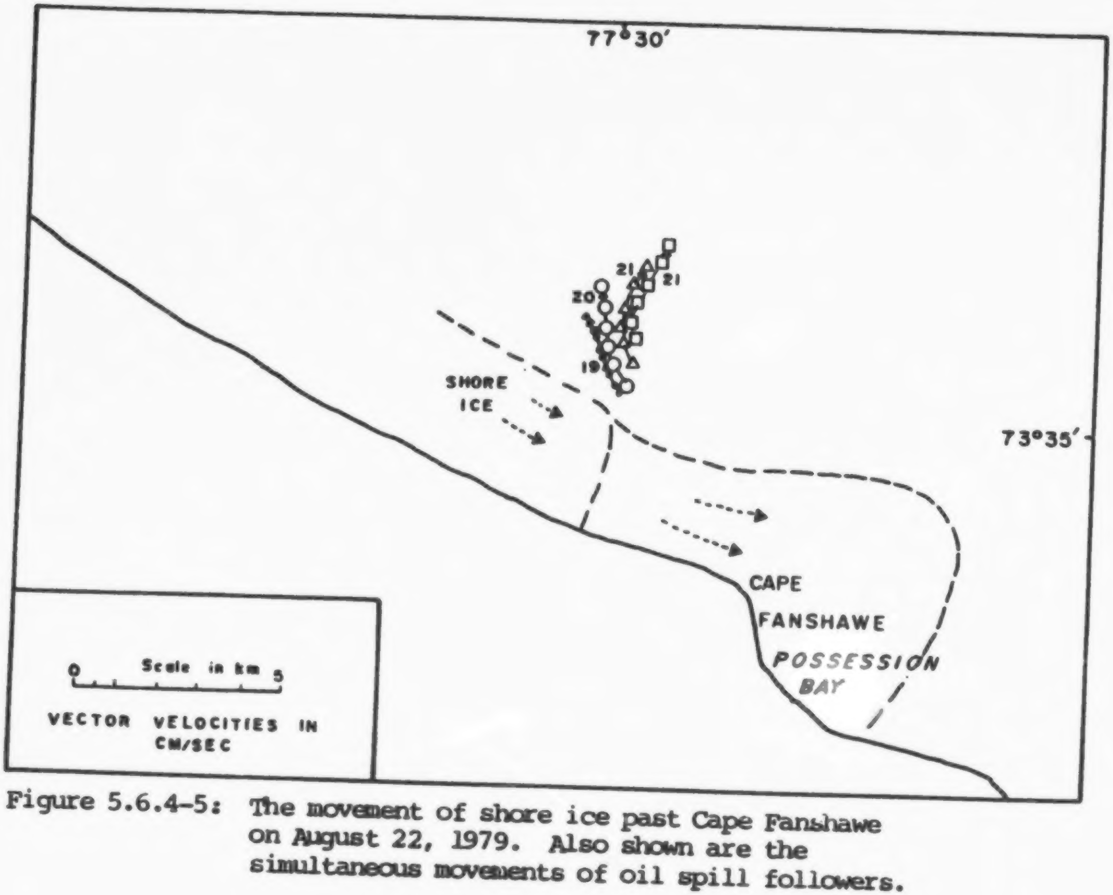

77°30'
73°35'
21
21
20
19
SHORE
ICE
CAPE
FANSHAWE
POSSESSION
BAY
0 Scale in km 5
VECTOR VELOCITIES IN CM/SEC

Figure 5.6.4-5: The movement of shore ice past Cape Fanshawe on August 22, 1979. Also shown are the simultaneous movements of oil spill followers.

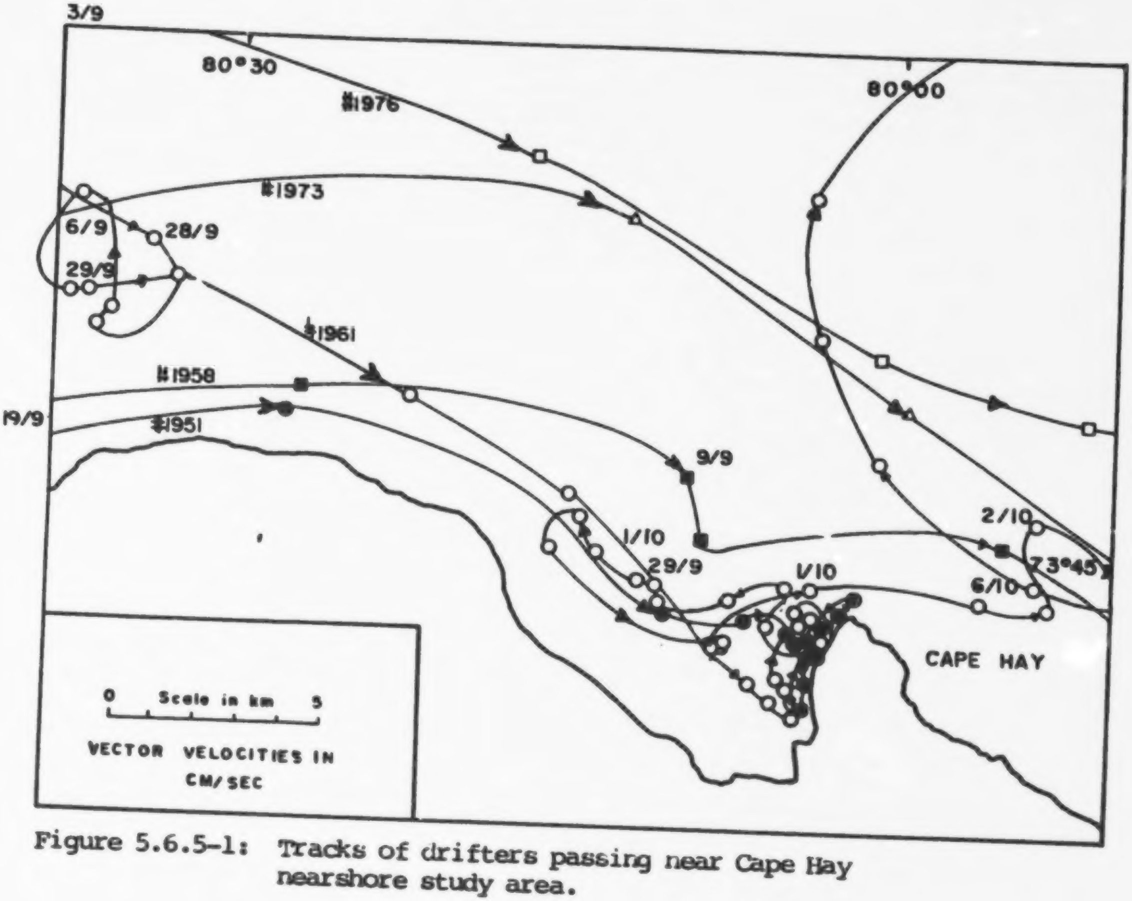

3/9
80°30
80°00
#1976
#1973
6/9
28/9
29/9
#1961
#1958
19/9
#1951
9/9
1/10
29/9
1/10
2/10
73°45
6/10
CAPE HAY
0 Scale in km 5
VECTOR VELOCITIES IN CM/SEC

Figure 5.6.5-1: Tracks of drifters passing near Cape Hay nearshore study area.

Surface Circulation

Oil spill followers were tracked on August 17, 22, and 23. Tracking was carried out at high tide on the latter two dates, while on August 17th, tracking was done during a period close to low tide. No direct measurements of tidal flow are available for this area.

Figure 5.6.4-4 is composite plot of the oil spill follower trajectories for the three measurement periods. The trajectory further offshore is drogued drifter 1974 which was in the area during the study period. The three oil spill follower trajectories nearest shore have been adjusted according to the 3% wind rule for the effect of a period of easterly winds winds on August 17. The wind on the other two days was calm. The oil spill followers nearshore moved to the northwest, alongshore, with speeds of 30 - 50 cm/sec. The oil spill followers further offshore showed a general northwesterly drift as well, but with an offshore component. The speeds of these drifters varied between 20 and 54 cm/sec. The oil spill followers on August 22 had the largest offshore component and the lowest total speeds. On August 15, drogued drifter 1974 moved offshore, then south (see Figure 5.6.4-4). If this can be considered synoptic with the oil spill followers, the general surface circulation was one of northwesterly flow nearshore, offshore flow 3 to 13 km from shore, and southeasterly flow beyond that (see Figure 5.6.4-4).

While oil spill followers moved northwest on August 22, shore ice moved alongshore from northwest to southeast (see Figure 5.6.4-5). Similar ice movement was observed on August 28 while temperature profiles were being taken. Southeasterly flow nearshore was also indicated in the track of drogued drifter 1958 on September 11 - 12, 1979 (Figure 5.6.4-1). Drifter 1958 moved slowly southeast past Cape Fanshawe and into Possession Bay. Then it turned north and moved about 15 km offshore before turning to the southeast again.

Summary

During the August 1979 study, the surface circulation within 5 km of shore was generally northwesterly at speeds of about 45 cm/sec. However, ice movement within several hundred meters of shore, on two occasions, was observed to be to the southeast. Between about 5 and 13 km of shore, the flow was offshore, becoming southeasterly 15 km offshore.

5.6.5 Cape Hay Nearshore Zone

Cape Hay is on the northwest coast of Bylot Island (Figure 5.6.5-1). To the west of Cape Hay is a bay which is fed by glacial runoff and further to the west are cliffs which house a large bird colony in summer. Just offshore of the study area is the strong, easterly Lancaster Sound outflow. Offshore flows are typically 75 cm/sec (see Section 5.2.3 for more detail).

Surface Circulation

In the summer of 1979, several drogued drifters passed near and through the study area (Fig. 5.6.5-1). Drifters 1973 and 1976 passed by about 8 km offshore at speeds of about 115 cm/sec. However, drifters 1951, 1958 and 1961 approached within 3 km of the cliffs and exhibited motions which were obviously related to nearshore effects. Their speeds were lower (50 - 90 cm/sec) and they tended to be drawn into the embayment just west of Cape Hay. 1958 was not drawn in completely; 1951 entered the embayment and grounded; 1961 entered the bay and remained for two days, in motion, before exiting. The motions of these drogued drifters suggest that the bay produces a relatively stagnant area just to the east of the cliffs. Water from immediately offshore can be drawn into this area with back-eddy-like motions occurring.

There has been earlier evidence of a westerly flow nearshore in the embayment mainly based on ice movement (Sekarak et. al., 1979). Aerial photos taken on August 28, 1958 also indicate that the nearshore flow east of the cliffs was to the west. In Figure 5.6.5-2, ice streams and meltwater patterns suggest westerly flow alongshore, and there are definite wakes on the western (lee) sides of the larger, presumably grounded, pieces of ice.

On September 6, 1979, two clusters of oil spill followers were tracked in the area of the embayment. Winds at the time were about 2 m/sec from the north. The cluster furthest offshore moved east at speeds of about 70 cm/sec, while the cluster deployed 2 km from the cliffs moved more slowly (30 cm/sec) and showed a tendency to turn to the right towards the embayment (Figure 5.6.5-3). While tracking was in progress, the ship drifted at speeds of up to 100 cm/sec to the east just offshore of the cluster furthest from shore.

Current profile measurements taken on September 9, at a point between the two OSF tracks, showed that the strong east-southeasterly surface flow of about 100 cm/sec extended to at least 38 m depth. A current meter mooring located near the release point of the offshore OSF cluster recorded strong east-southeasterly flow (55 cm/sec at 35 m) on September 6. Current speeds at meters 250 m and 450 m depth were east-southeasterly as well, with speeds of 22 and 8 cm/sec respectively.

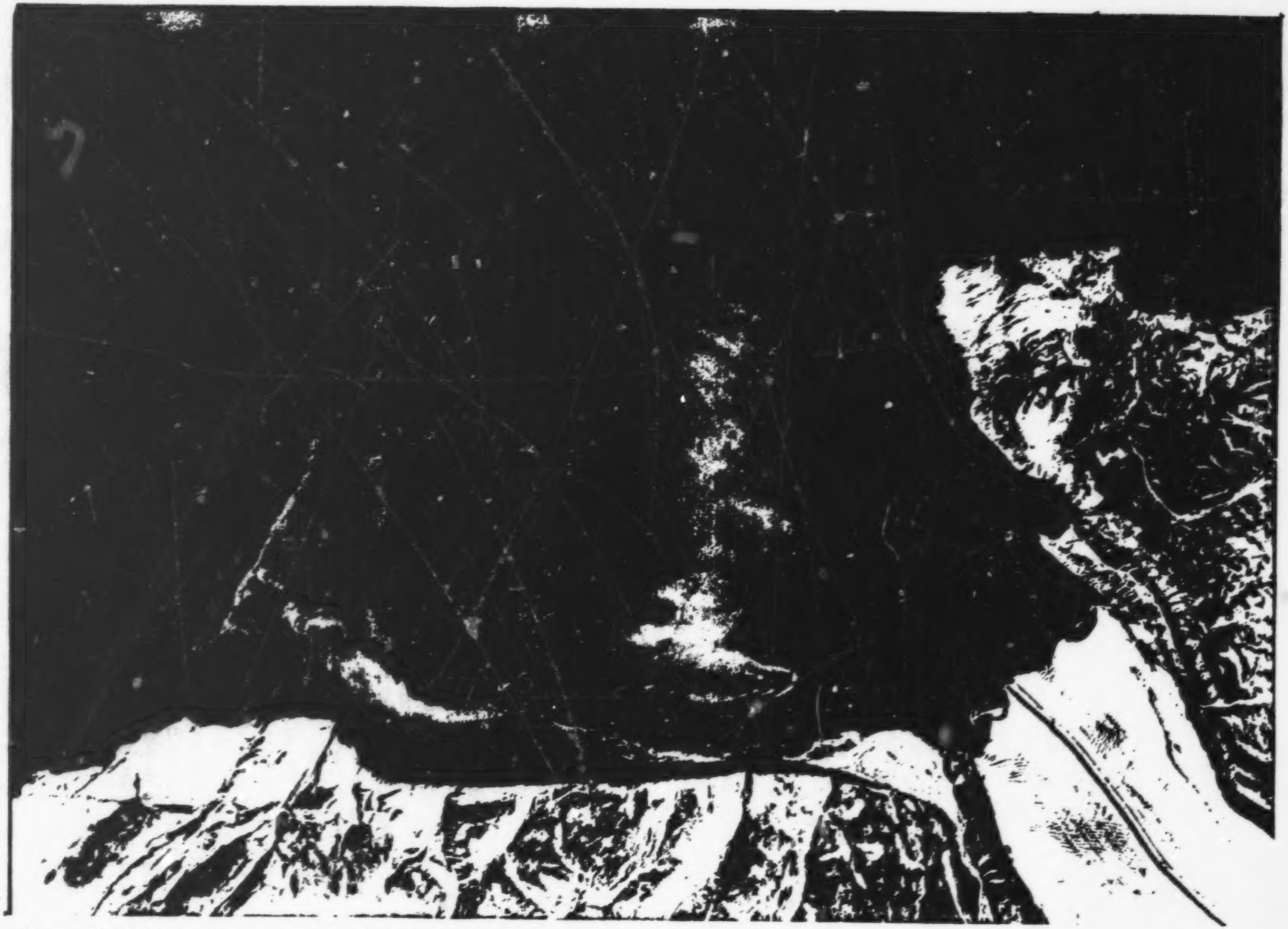


Figure 5.6.5-2: Cape Hay nearshore study area. August 28, 1958 photo from 30,000 feet. National Air Photo Library, Ottawa.

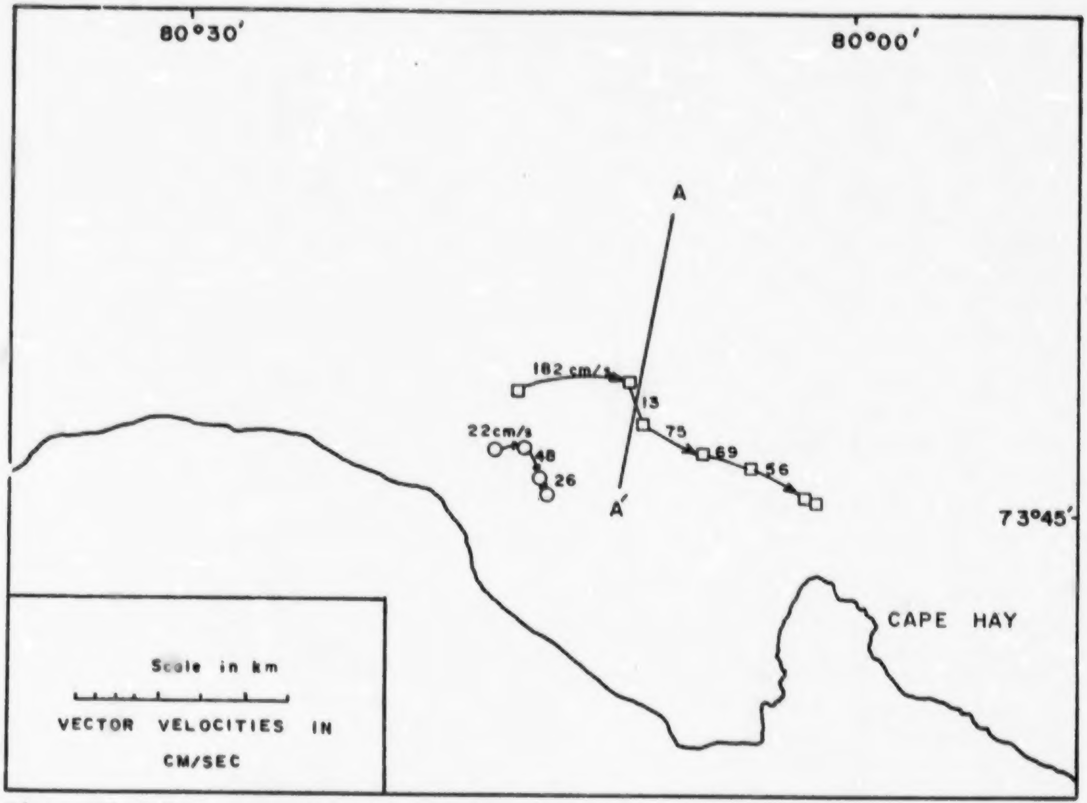

80°30'
80°00'
A
A'
182 cm/s
13
75
69
56
22cm/s
48
26
73°45'
CAPE HAY
Scale in km
VECTOR VELOCITIES IN CM/SEC

Figure 5.6.5-3: Tracks of two oil spill followers off Cape Hay, September 6, 1979.

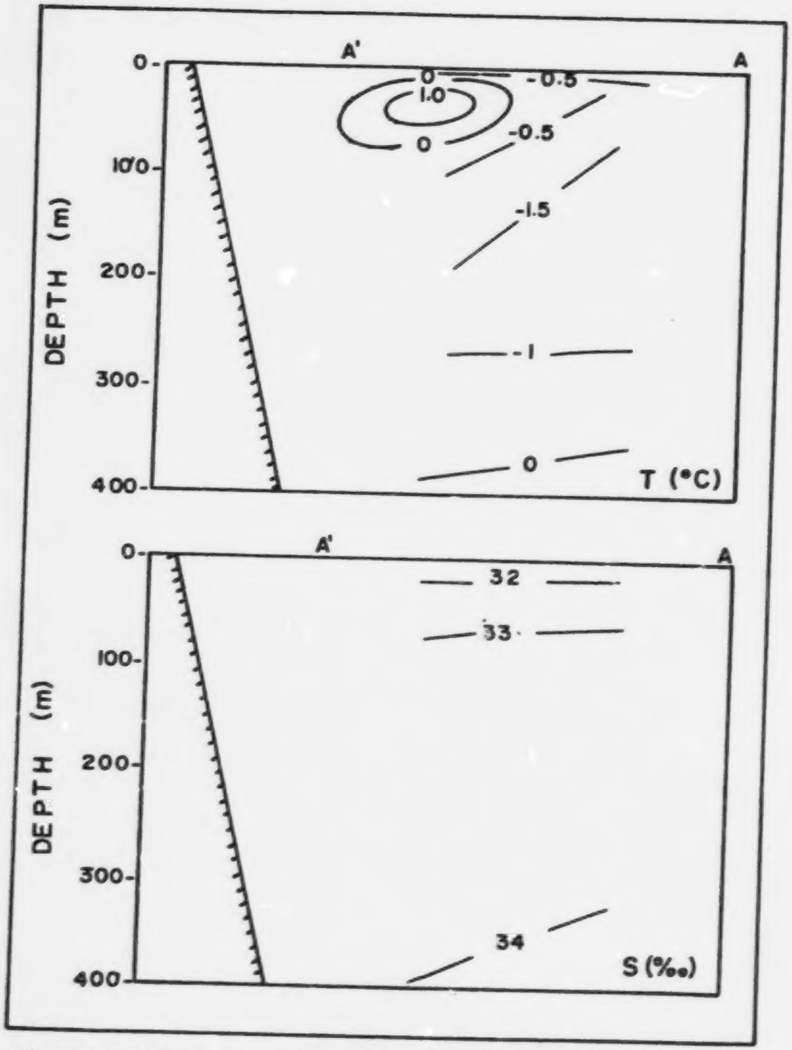


Figure 5.6.5-4: Vertical section of temperatures and salinities along section indicated in Figure 5.6.5-3.

Water Properties

On September 9, 1979, four CTD stations were completed in this area. Figure 5.6.5-4 shows the vertical temperature and salinity structure for line A-A' (Figure 5.6.5-3). The influence of the warmer, saline Atlantic Water can be seen at depths near 400 m. Above is Arctic Water; the warm water at 30 m is probably part of the warm surface water found offshore in Baffin Bay during summer. The aerial photo (Figure 5.6.5-2) of 1958 shows that the runoff from the glacier forms a thin surface layer, and spreads over the entire embayment, stopping at a line roughly joining Cape Hay to the edge of the cliffs. This line coincides approximately with the edge of the strong offshore flow.

Summary

The Cape Hay study area is characterized by weak and variable flows in the bay immediately to the west, with frequent westerly nearshore movements, while offshore is the strong eastward flow of the Lancaster Sound outflow. Drifters indicate that water parcels approaching within about 3 km of the cliffs tend to be drawn towards the bay with back-eddy-like features occurring.

5.6.6 Summary of Nearshore Circulation Features

The nearshore circulation studies at Cape Warrender, Cape Fanshawe and Cape Hay reveal complex circulation features with small spatial scales. These include eddy-like motions of scales of 5 km, and strong lateral velocity shears.

One major forcing mechanism is the strong flows located immediately offshore in many parts of the study area. These offshore flows drive flows in the nearshore zone; however, the effect of the coastline is evident in strong lateral velocity shears across the nearshore zone and occasional small back-eddy circulation features which would be expected in lateral boundary layers.

The local winds are found to vary significantly with distance offshore at Cape Warrender; winds at the coastline are not representative of winds at locations a few kilometres offshore. As well, strong local winds may develop off some of the glacial valleys and other indentations in the rugged eastern Arctic coastline. These local winds could alter the circulation patterns in the adjacent portion of the nearshore zone.

Tidal currents can be significant in nearshore zones and may be enhanced due to internal tides developing in response to the surface tidal motions driving isophecnals over bathymetric gradients (section 5.4). Evidence of these effects is found in the current meter data and drogued drifter motions obtained near Cape Warrender, as well as at current meter moorings off Cape Hay. Enhanced K_1 tidal flows were found in both areas as compared to the offshore tidal currents.

Freshwater of local origin may be of importance in determining nearshore circulation features. The freshwater input due to local sea-ice melt or land runoff results in a thin brackish upper layer overlaying a more saline layer of Arctic Water. Along the interface, internal waves develop with periods of the order of 10 minutes. Also, the presence of lateral density gradients resulting from the lower salinity water being concentrated nearshore can result in geostrophic flows. Due to the other driving mechanisms in the area, a simple geostrophic balance may not be attained; however, movement along the geostrophic direction could contribute to the net current.

One of the striking circulation features observed in the nearshore studies was the presence of nearshore flows in opposite directions to those of the strong offshore currents. Instances of such flow reversals were observed at all three nearshore study sites; the reversals do not appear to be permanent, but reflect the changing balance of the forcing mechanisms.

One of the striking circulation features observed in the nearshore studies was the presence of nearshore flows in opposite directions to those of the strong offshore currents. Instances of such flow reversals were observed at all three nearshore study sites; the reversals do not appear to be permanent, but reflect the changing balance of the forcing mechanisms.

The knowledge gained by studying these three sites can now be used to help anticipate conditions that could be encountered in other nearshore zones of the study area. This is not to imply that a complete understanding of nearshore processes exists. Even at Cape Warrender, where more data was gathered than at the other sites, the description of the circulation patterns is far from complete. The complicated processes which occur in these zones will require further study before they will be fully understood.

5.7 Seasonal Variations

The five current meter moorings deployed in the early autumn of 1978 and recovered the following summer are the first extensive set of direct measurements of winter currents ever obtained in Baffin Bay. From these data of 10 months duration, together with the two months of summer 1978 data, nearly one complete year of time series data is available for four stations: 1, 2, 10 and 13. (The winter mooring location designated as station 8a was moved a considerable distance (20 km) from the summer site and cannot be considered as having the same location).

In this section, these data are used to examine seasonal changes in the circulation and water properties. At 35 m depth, data is available for stations 2 and 13: the rotor was lost from the current meter at station 1 five days following deployment and the uppermost current meter at station 10 failed shortly after deployment, resulting in no 35 m winter current data at these two sites. The 35 m data from station 8a will be considered as well for the 10-month period it was in place. At 250 m depth, stations 1, 2, 10 and 13 have complete records, while 10 months of datra are available for station 8a. Data was collected at the nominal depth of 500 m at stations 8a, 10 and 13, and at the nominal depth of 400 m at station 1. The deepest current meter time series record was obtained at station 13 at a nominal depth of 750 m; for the August - September 1978 period no speed data is available, due to a circuit malfunction in the instrument.

5.7.1 Seasonal Variations of Currents

In studying the seasonal variations of the circulation the locations of the current meter moorings relative to the major summer circulation features may be of importance. Mooring stations 1 and 2 (Figure 5.7-1) are both located to the east of Devon Island in the Baffin Current, prior to its entering eastern Lancaster Sound (see Section 5.2.2). Station 8a is located within the current flowing out of eastern Lancaster Sound, which arises from a combination of the intrusive current and flows from western Lancaster Sound (see Section 5.2.3). Station 10 is located in an area of generally weak westerly flows beyond the outer edge of the Baffin current flowing into Lancaster Sound.

In order to examine the seasonal variations, the time series data was divided into monthly intervals. For each month, the mean was computed for each measured quantity. The mean current components were combined to produce a vector-averaged monthly mean current, as displayed in Figure 5.7-1.

Seasonal variations are evident in the monthly mean currents at all mooring locations at some depths. Maximum values of the current are measured in the months August to October, inclusive, while the minimum currents generally occur in the months February to May, inclusive. These seasonal changes in ciraculation appear to reflect the changes in ice cover with the maximum mean current coinciding with minimum ice cover (August to October) and the minimum mean current occurring prior to local ice break-up. At stations 1, 2, 8 and 10, considerable amounts of open water appeared in June and July, 1979, and the mean current velocity increased. At station 13, the ice cover persisted until the end of July and a corresponding shift in the duration of the minimal monthly current occurred extending from February to July, inclusive.

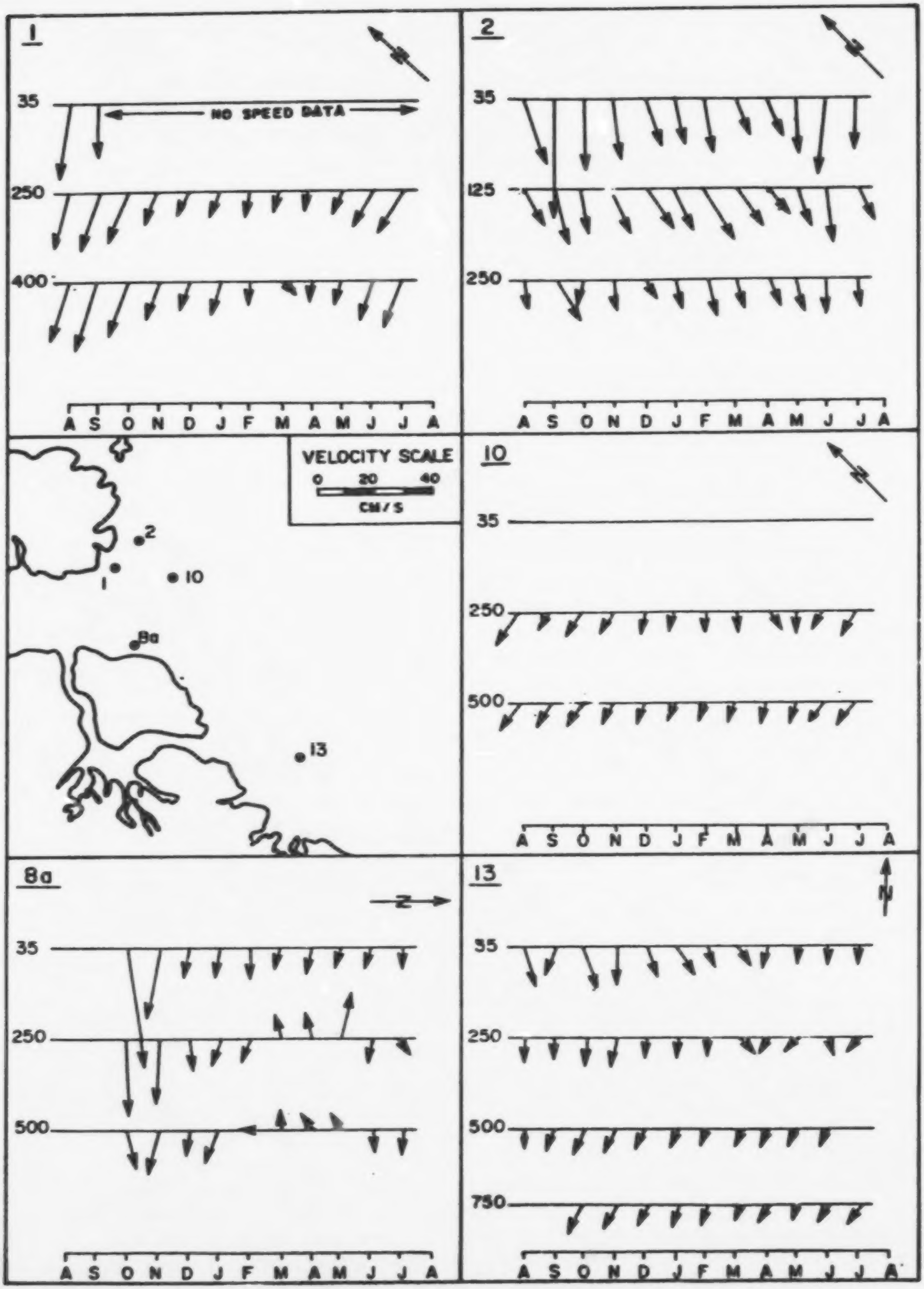


Figure 5.7-1: Monthly vector-averaged velocities of current meter data from August 1978 to July 1979. The orientation of the vectors is indicated by the direction of geographical north in each plot.

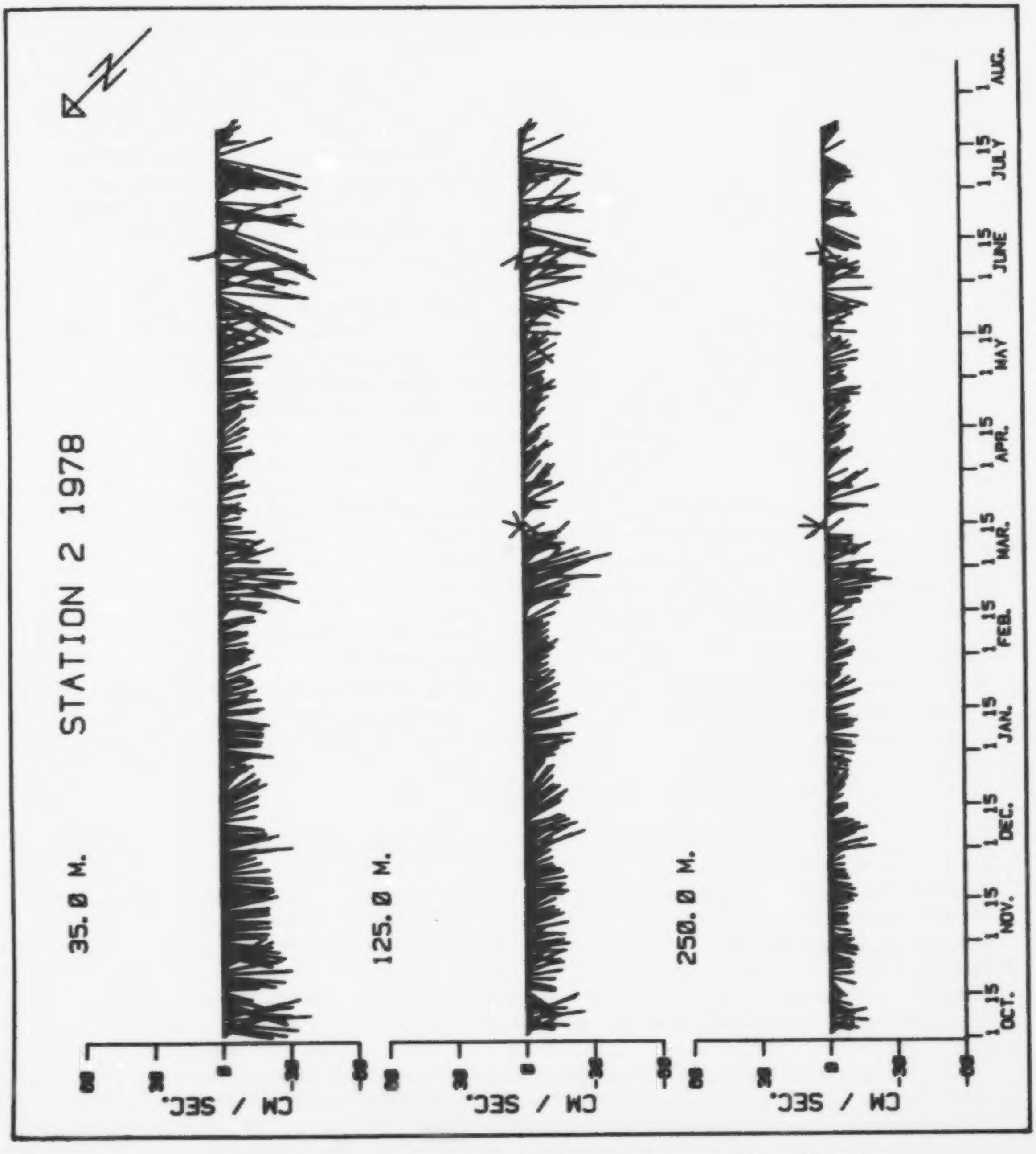


Figure 5.7.2: The currents at station 2 after low pass filtering to remove daily and higher frequency variations.

Despite the decreased amplitude of the currents in the winter months, the overall circulation pattern remains much the same as for the summer months. The southerly to southwesterly flow along the Devon Island at stations 1 and 2, the westerly flow at station 10, and the southerly flow off Baffin Island at station 13 are evident in both seasons. Only in the deeper current data at station 8a is a marked change in the mean monthly currents observed: here the currents at 250 m and 500 m depth reverse to westerly in the months of March, April and May, while at 35 m depth they remain generally easterly with reduced strength.

Pronounced seasonal variations are apparent in all current meter time series data obtained at nominal depths of 35 m (three stations). At the larger nominal depths of 250 m and 400-500 m, the presence of seasonal variations in the circulation varies according to location. At stations 1 and 8a, very marked seasonal variations occur in the currents at depths of 250 m and 400 m (station 1) or 500 m (station 8a): mean monthly velocities at station 1 decline in the months February to May to less than one-third of their summer magnitudes while the mean monthly velocities at station 8a are opposite in direction in the months of March to May to the net flow of the summer months. The seasonal variations in the deeper currents at stations 10 and 13 are less pronounced. Here, the generally weaker currents as measured in summer are further reduced in winter to approximately one-half of their summer levels. No significant seasonal variations are apparent at 250 m depth at station 2, even though they are apparent at both 35 m and with a reduced amplitude at 125 m at this location. While variations do occur at 250 m depth in the monthly mean velocities, they appear to vary over shorter time periods than one year. The causes of these differences in the amplitude of seasonal variations among the various mooring locations are not understood. They may be related to differences in the local circulation patterns or the degree of vertical stratification present at each site as discussed below.

Along with the decrease in the monthly mean velocities during periods of extensive ice cover, the level of synoptic variations appears to decrease as well. As an example, the low-passed (half amplitude passed at periods of 3 days) currents at station 2 are presented in Figure 5.7-2. At all depths the synoptic vatiations are lower in amplitude in winter than in summer. However, while they are reduced, synoptic variations do persist through periods of seasonal ice-cover.

The diminished circulation measured at all five of the mooring stations during the ice-covered months strongly suggests that the cyclonic circulation of northwestern Baffin Bay is generally reduced during this period. Because of the high risks of operating current meter moorings throughout the extended Arctic winter, the number of measurement sites was necessarily limited and therefore the spatial resolution of the winter 1978-79 data is reduced in comparison with the data obtained in the summer programs. For this reason, it is not possible to define the width of the major circulation features from the winter data. Thus, it is not possible to determine whether the rather narrow but intense summer circulation features retain the same spatial characteristics through the ice-covered period. The possibility exists, for example, that even though the intensity of the circulation decreases, as indicated by the winter 1978-79 data, the width of the currents may increase resulting in net transports comparable to those of the summer.

5.7.2 Seasonal Variations of Temperature and Salinity

Subsurface temperature and salinity measurements were obtained with the Aanderaa RCM-4 current meters used on the five moorings operational throughout the winter of 1978-79. The accuracy of these temperature and salinity measurements is inferior to that of the Guildline CTD data, obtained during the shipboard-based studies in the summer months. Manufacturer's specifications give the temperature accuracy as ±0.15°C, while the accuracy of the conductivity cell is not provided. A comparison of laboratory calibration data obtained for Aanderaa RCM-4 current meters before and after the summer 1978 field program suggests that the conductivity measurements are reliable to 0.11 mmho/cm or better in fourteen out of fifteen cases (Fissel, 1980a). Using these figures, the combined uncertainty in salinity measurements amounts to 0.2‰.

A strong seasonal cycle is clearly evident in the temperature data obtained at the nominal depth of 35 m. For the four locations where 35 m temperatures are available (stations 1, 2, 8a and 13), the monthly mean temperatures decline from peak summer values of 0.4 to -1.0°C to temperatures near the freezing point of sea-water, -1.8°C during the months October to May, inclusive (Figure 5.7-3). During the period of near freezing point temperatures at 35 m depth, the temporal variations of the temperatures become very low (approximately 0.05°C or less). These seasonal changes are very clearly related to the seasonal growth and decay of ice in the region. With the reduced solar insolation in late summer and autumn, the surface water layer cools and ice begins to form.

One consequence of ice formation is the extrusion of heavy salty water which results in vertical mixing of the water column to increasingly large depths as ice growth continues. This process is well illustrated by the mean-monthly temperature and salinity variations at station 2 (Figure 5.7-3 and 5.7-4).

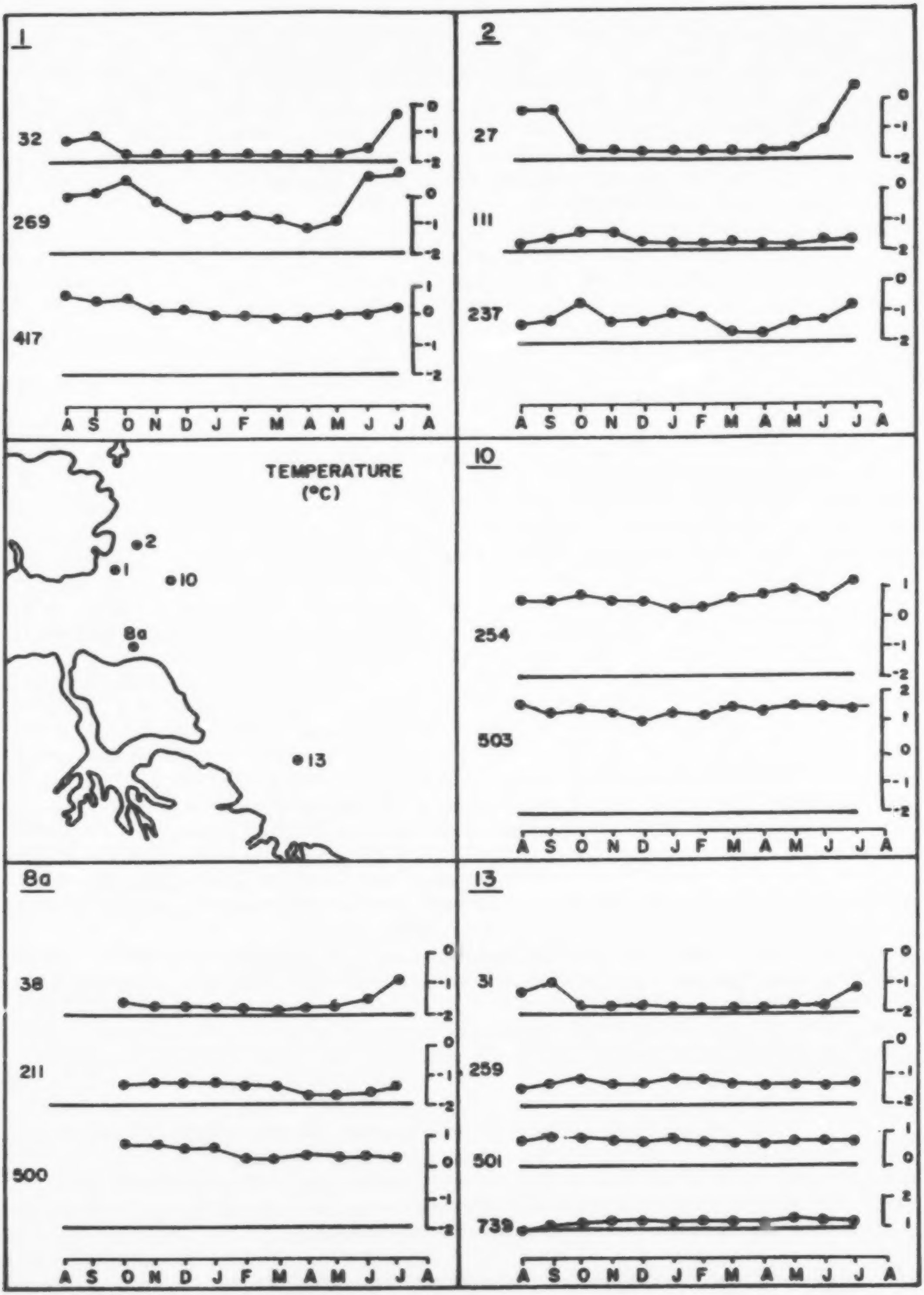


Figure 5.7-3: Monthly mean temperatures of current meter data from August 1978 to July 1979. The numbers beside each time series indicate the actual mean depth of the current meter.

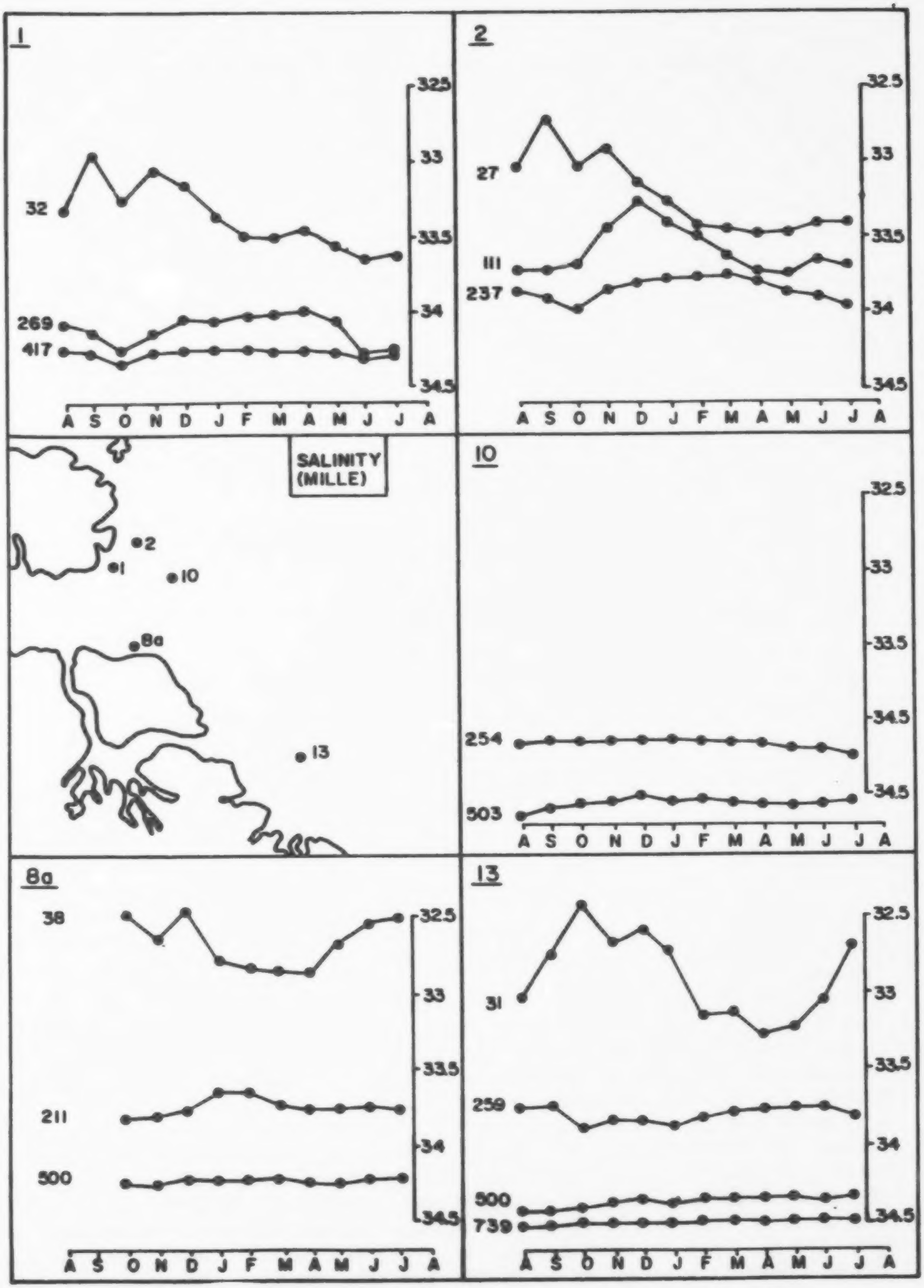


Figure 5.7.4: Monthly mean salinities of current meter data from August 1978 to July 1979. The numbers beside each time series indicate the actual mean depth of the current meter. Note that the salinity decreases upwards rather than following the normal convention.

Surface cooling and ice formation is apparent in the 27 m measurement by October both from the temperatures being near the freezing point and the increase in salinity and hence, density of the water. This convective penetration process reaches the next current meter (depth of 111 m) in December as indicated by the characteristic decline in temperature to near the freezing point and increased salinities. There is some evidence that the convective penetration may have extended to the level of the deepest current meter at station 2, 237 m, in the months of March and April; however, the fact that the temperature rose well above the freezing point in June and July at this depth suggest that horizontal advection may be of importance here and the earlier decline of temperatures in March and April may result from horizontal movements rather than vertical exchanges. With the increasing insolation in spring, ice growth ceases followed by the melting and break-up of the sea-ice cover. The temperatures of the upper current meter respond by increasing and are followed by decreasing salinities due to the wind mixing fresher surface water downwards.

The seasonal changes in the Arctic water due to the cycle of ice growth and decay described above may have some importance to the circulation. Examination of the vertical structure of salinity and hence density at station 2 (Figure 5.7-4) indicates that a strong seasonal cycle occurs in the stratification of the Arctic Water layer. In late summer, the stratification reaches a maximum value and is subsequently reduced by convective penetration associated with ice growth. In February and March, the net vertical density difference between 27 m and 237 m at station 2 is only one-half of the summer value. With the reduction in vertical stratification, a decline in the level of the baroclinic circulation of the Arctic Water layer would seem reasonable. This is, indeed, the case at station 2, as shown by the variation of monthly mean currents (Figure 5.7-1).

Seasonal variations in temperature and salinities decline markedly with depth. At the nominal depths 400, 500 and 750 m, the range of variations in monthly mean temperature and salinity is comparable to accuracies of the current meter instrumentation. There is no evidence of significant seasonal variations at these depths. At the nominal depth of 250 m, the amplitude of variations in the monthly mean temperature and salinity values is intermediate between that observed at greater depths and that observed at 35 m nominal depth. At stations 1 and 2, and to a lesser extent at station 8 and 13, the temperature and salinity increased in late summer, reaching maximum values in October and subsequently declined until the period of March to May. The correlations in the changes of temperature and salinity suggest that a seasonal shift in the influence of the Arctic Water and Atlantic Water may occur at depths near 250 m. This is most notable at station 1 (actual mean depth of 269 m) where from November to March, the mean monthly temperature-salinity (T-S) values are those of Arctic Water, while for the months of June to October, the T-S values suggest that Atlantic Water is more prevalent. At the other stations, the actual depth of the current meters is less and the mean monthly T-S values are those of Arctic Water, but similar seasonal variations are observed with the exception of station 10.

In summary, significant seasonal variations of the currents, temperatures and salinities occur in the upper portion of the Arctic Water layer in northwestern Baffin Bay, as measured by current meters at nominal depths of 35 m and 125 m. The seasonal variations of the currents are characterized by reduced flows in the ice-covered period with minimum values in the months February to May. Such seasonal variations of the currents at depths of 250 m or greater vary according to location: at one station, seasonal variations occurred to depths of 750 m, while at another station, significant seasonal variations were evident only at depths less than 250 m. The amplitude of seasonal variations of temperature and salinity generally decreases with increasing depth. At nominal depths of 400 m, these variations in the monthly mean values were less than the accuracy of the measurements.

5.8 Year to Year Variations in the Surface Circulation

5.8.1 Lancaster Sound

The data upon which a measurement of the recent year-to-year variations in the circulation of Lancaster Sound can be based consists of hydrographic measurements collected on several cruises between 1954 and 1970, as well as the results of the 1978 and 1979 studies. The earlier data has been drawn from cruise results filed at the Marine Environmental Data Service (MEDS) in Ottawa. It is presented here as charts of the dynamic topography of the surface relative to 300 dbar. 300 dbar was chosen as the reference level because portions of the approaches to Lancaster Sound (east of Devon Island) are between 300 and 500 meters deep. Since it appears that the major part of the shear in the water column occurs above 300 meters depth (Section 3), 300 dbar was chosen as the reference level to avoid the necessity of making extrapolations of the reference level to depths below the sea bottom. Data was used from the following years summarized in Table 5.8-1:

Table 5.8-1

Data Used For Year-to-Year Comparisons

Year	Number of Stations	Dates of Occupation
1954	11	August 2-14
1956	11	Sept. 23 - Oct. 1
1957	23	Aug. 20 & Sept. 18-25
1960	28	Sept. 15-24
1961	31	Sept. 13-19
1962	33	Oct. 2-7
1963	13	Oct. 3-7
1970	30	July 24 - Aug. 6

Data was collected in this area in years other than those listed in Table 5.8-1, however the cruises listed above are the only ones for which sufficiently dense coverage existed to derive good comparisons. The discussion will therefore be limited to the data sets listed in Table 5.8-1. Dynamic topographies drawn from these data are shown in Figures 5.8-1 - 5.8-8, starting in 1954 and progressing to 1970. The contour interval in each case is two dynamic centimetres.

With data which is relatively coarse (in most cases) and widely spaced in time, it will be possible to examine only the larger-scale features of the flow. The most important characteristic of the flow observed in the eastern part of Lancaster Sound in 1978 and 1979 was the intrusive current (described in Section 5.2.3). It may be seen in various, more or less well-defined forms in 6 of the 9 data sets shown. A note is in order here about the contouring and interpretation of the data. In many cases where a complicated, multi-featured surface has to be drawn from a set of discrete measurements, ambiguities may arise in the way the contour lines are drawn. Often more than one set of contour lines may be drawn using the same set of points. Without additional information, there is frequently no logical reason to choose one interpretation over the other. In the case of the data presented here, the interpretation showing an intrusive current pattern has been used whenever more than one pattern was possible.

An intrusive current is definitely evident in the data from 1956 (Figure 5.8-2), 1957 (Figure 5.8-3), 1958 (Figure 5.8-4), and 1962 (Figure 5.8-6). It was probably present in 1961 (Figure 5.8-5) and 1970 (Figure 5.8-8) although the data sets from those years do not give sufficient coverage to adequately define the current. It is possible to interpret what data there are, however, as being consistent with the presence of such a current. Data collected in 1954 (Figure 5.8-1) do not show any instrusive current

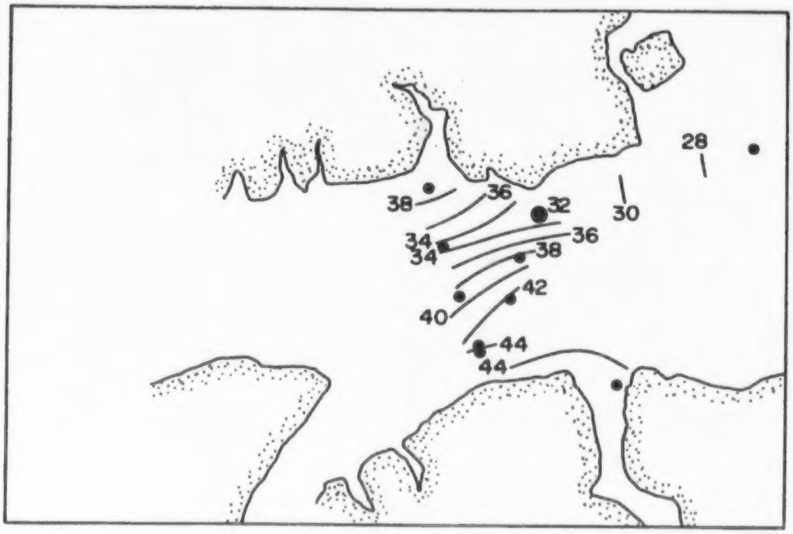

28
30
32
36
38
34
34
36
38
40
42
44
44

Figure 5.8-1: Dynamic topography of the surface relative to 300 dbar, August 2-12, 1954 in Lancaster Sound.

Table 5.8-1

Data Used For Year-to-Year Comparisons

Year	Number of Stations	Dates of Occupation
1954	11	August 2-14
1956	11	Sept. 23 - Oct. 1
1957	23	Aug. 20 & Sept. 18-25
1960	28	Sept. 15-24
1961	31	Sept. 13-19
1962	33	Oct. 2-7
1963	13	Oct. 3-7
1970	30	July 24 - Aug. 6

Data was collected in this area in years other than those listed in Table 5.8-1, however the cruises listed above are the only ones for which sufficiently dense coverage existed to derive good comparisons. The discussion will therefore be limited to the data sets listed in Table 5.8-1. Dynamic topographies drawn from these data are shown in Figures 5.8-1 - 5.8-8, starting in 1954 and progressing to 1970. The contour interval in each case is two dynamic centimetres.

With data which is relatively coarse (in most cases) and widely spaced in time, it will be possible to examine only the larger-scale features of the flow. The most important characteristic of the flow observed in the eastern part of Lancaster Sound in 1978 and 1979 was the intrusive current (described in Section 5.2.3). It may be seen in various, more or less well-defined forms in 6 of the 9 data sets shown. A note is in order here about the contouring and interpretation of the data. In many cases where a complicated, multi-featured surface has to be drawn from a set of discrete measurements, ambiguities may arise in the way the contour lines are drawn. Often more than one set of contour lines may be drawn using the same set of points. Without additional information, there is frequently no logical reason to choose one interpretation over the other. In the case of the data presented here, the interpretation showing an intrusive current pattern has been used whenever more than one pattern was possible.

An intrusive current is definitely evident in the data from 1956 (Figure 5.8-2), 1957 (Figure 5.8-3), 1958 (Figure 5.8-4), and 1962 (Figure 5.8-6). It was probably present in 1961 (Figure 5.8-5) and 1970 (Figure 5.8-8) although the data sets from those years do not give sufficient coverage to adequately define the current. It is possible to interpret what data there are, however, as being consistent with the presence of such a current. Data collected in 1954 (Figure 5.8-1) do not show any instrusive current

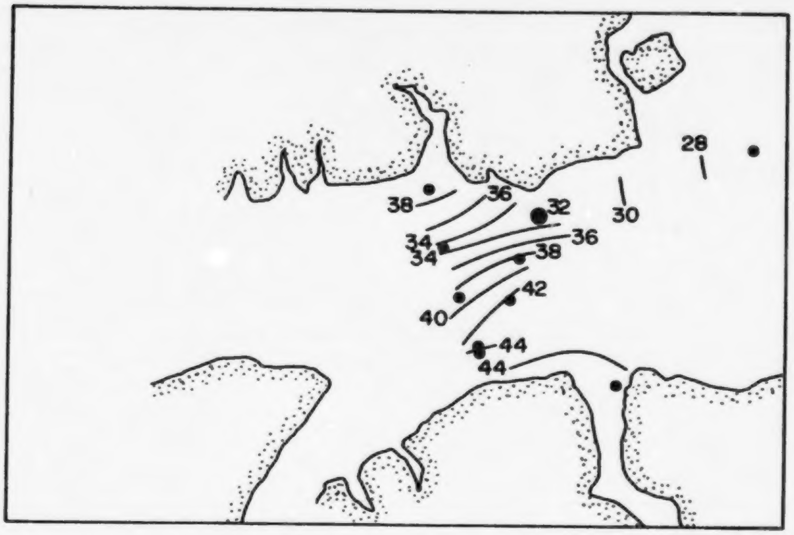

28
30
32
36
38
36
34
34
36
38
42
40
44
44

Figure 5.8-1: Dynamic topography of the surface relative to 300 dbar, August 2-12, 1954 in Lancaster Sound.

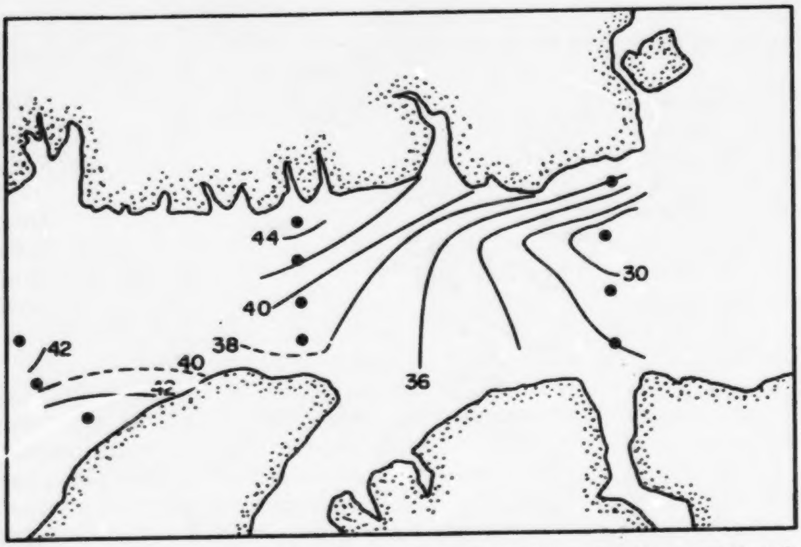

44
40
42
38
40
42
36
30

Figure 5.8-2: Dynamic topography of the surface relative to 300 dbar, September 23 to October 1, 1956 in Lancaster Sound.

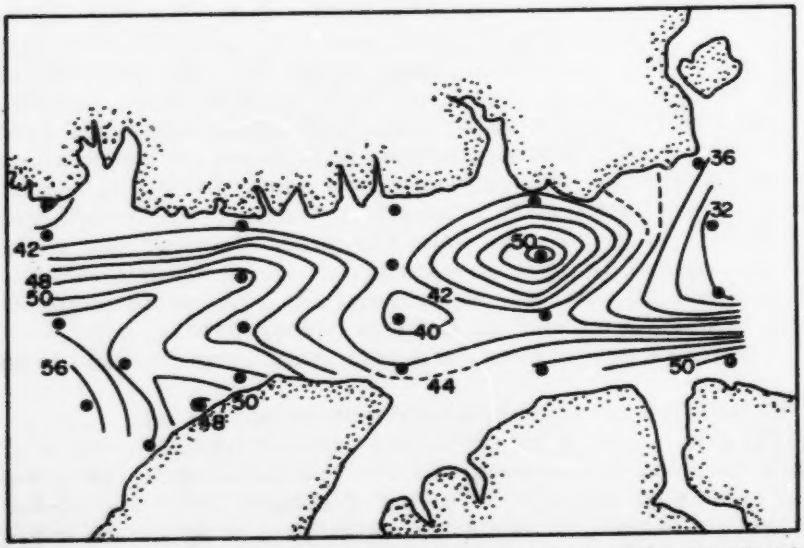

36
32
42
48
50
50
42
40
56
44
50
50
48

Figure 5.8-3: Dynamic topography of the surface relative to 300 dbar, August 20 and September 18-25, 1959 in Lancaster Sound.

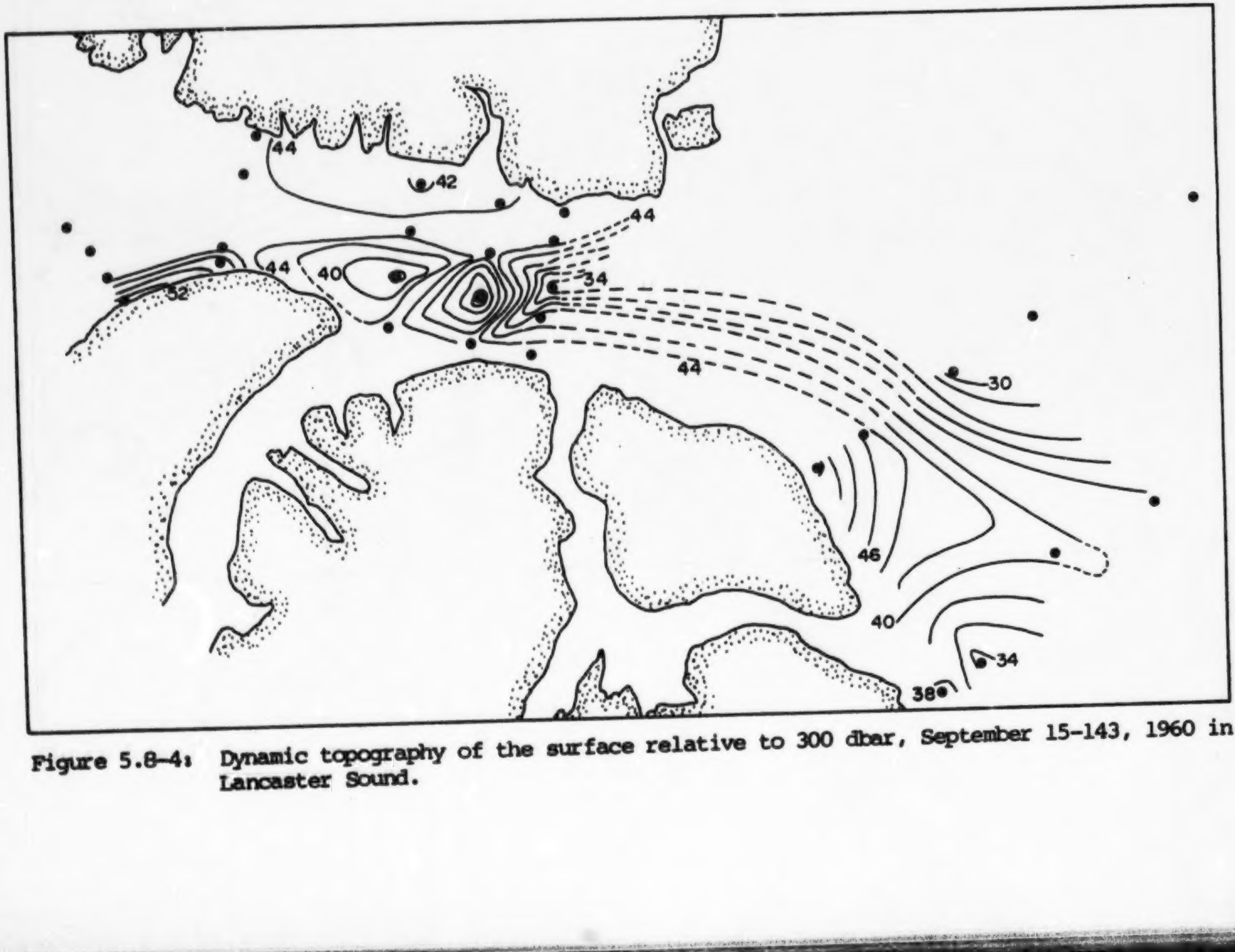

44
42
44
44
40
34
32
44
30
46
40
34
38

Figure 5.8-4: Dynamic topography of the surface relative to 300 dbar, September 15-143, 1960 in Lancaster Sound.

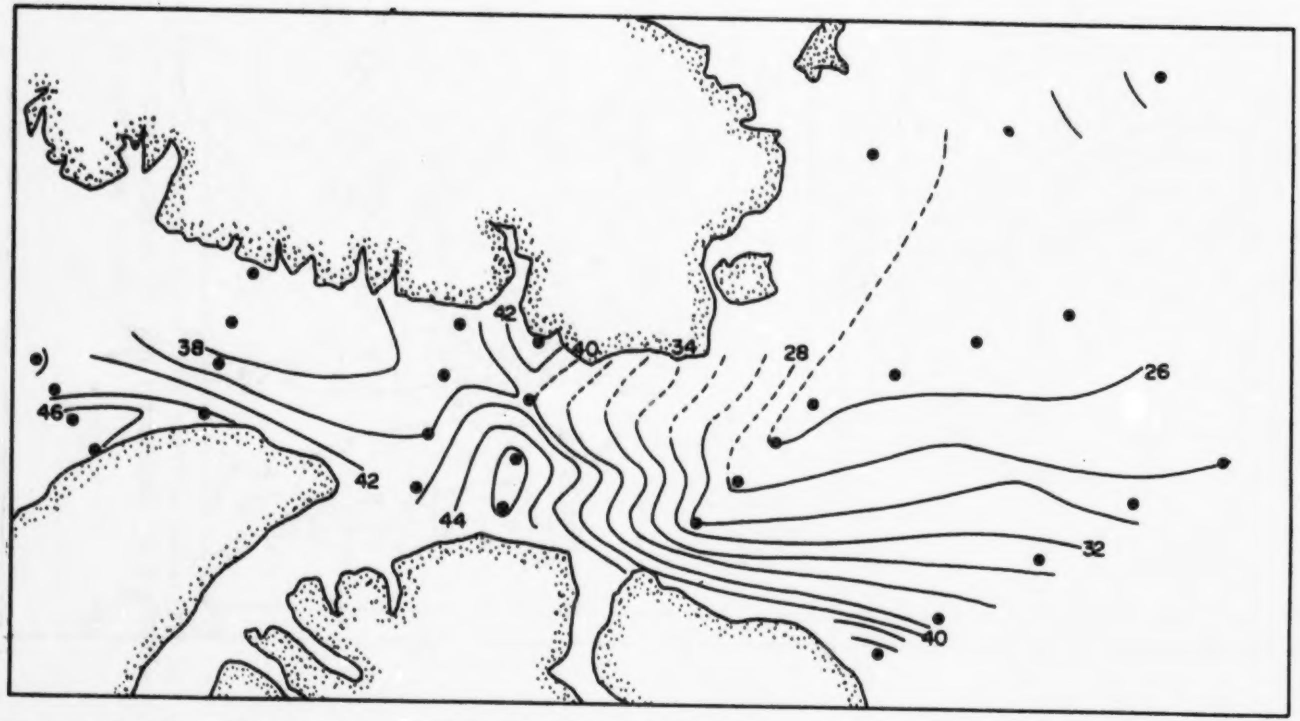

26
28
32
34
40
42
38
46
44
42
40

Figure 5.8-5: Dynamic topography of the surface relative to 300 dbar, September 13-19, 1961 in Lancaster Sound.

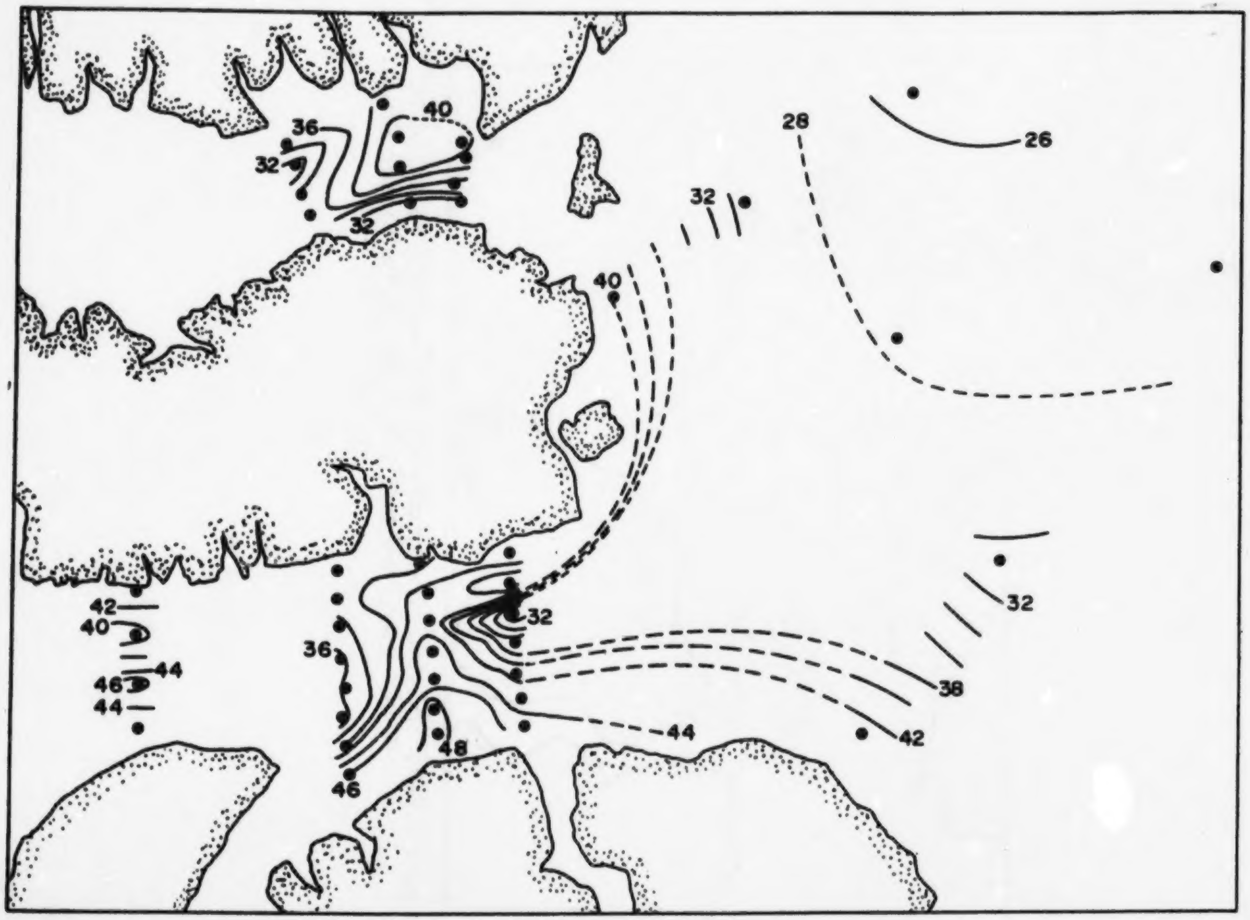

40
36
32
32
28
26
32
40
32
42
40
44
46
44
36
38
32
44
42
48
46

Figure 5.8-6: Dynamic topography of the surface relative to 300 dbar, October 2-7, 1962 in Lancaster Sound.

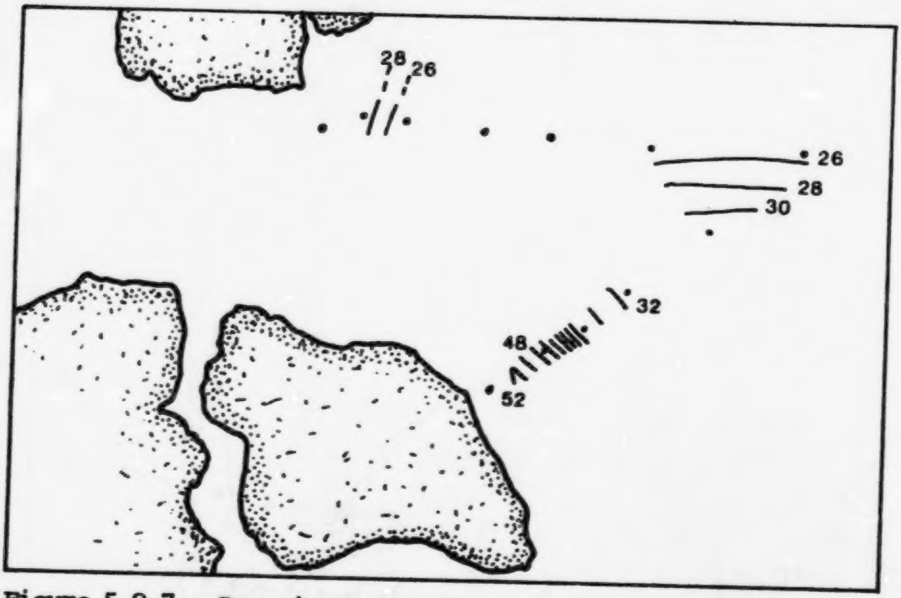

28
26
26
28
30
32
48
52

Figure 5.8-7: Dynamic topography of the surface relative to 300 dbar, October 3-7, 1961 in Lancaster Sound.

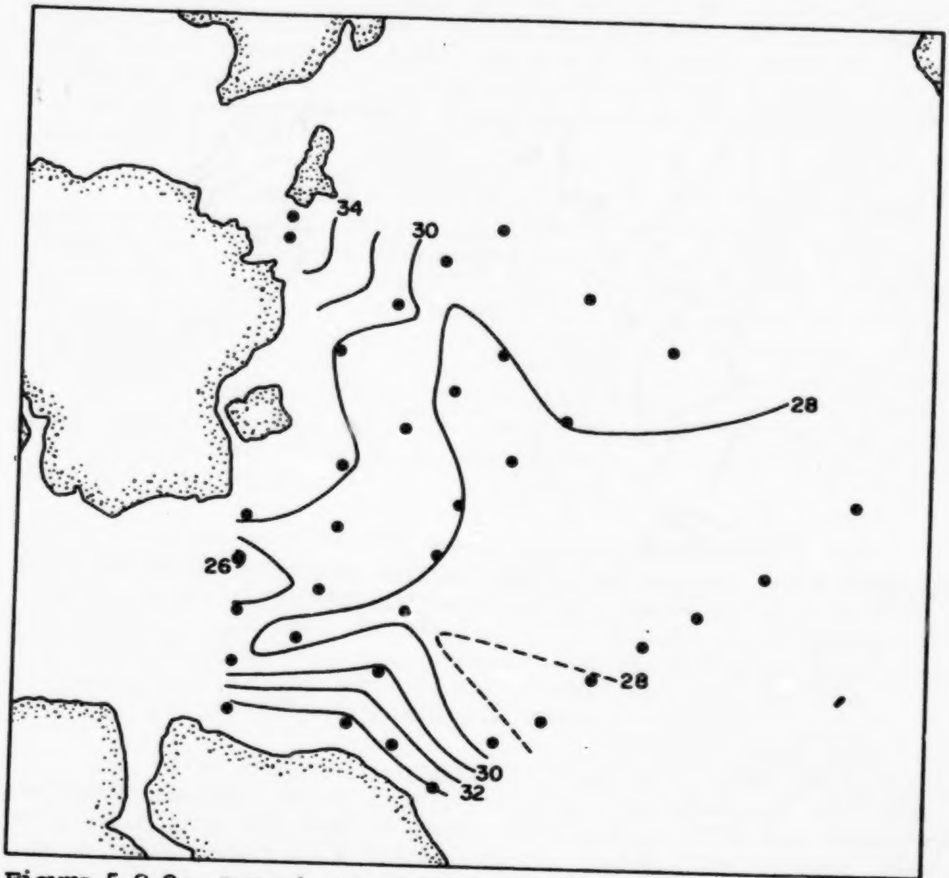

34
30
28
26
28
30
32

Figure 5.8-8: Dynamic topography of the surface relative to 300 dbar, July 24 to August 6, 1970 in Lancaster Sound.

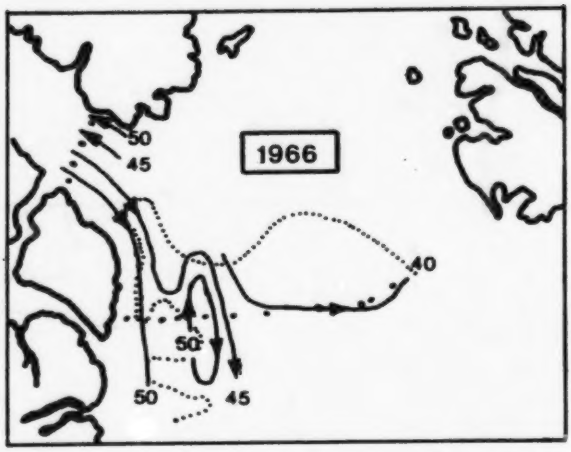

1966
50
45
40
50
50
45

Figure 5.8-9: Dynamic topography of the surface relative to 500 dbar, 1966 (Muench, 1971) in Lancaster Sound.

as such, although there are only 8 stations and they are all rather far removed to the west. They portray an easterly flow over most of the Sound, perhaps including a northward meander just west of Cape Warrender. Southerly flow is shown off Cape Sherard, however, which may indicate that some form of intrusive current existed in the entrance to the Sound. While one may imagine that such a current could have existed, there is not sufficient data to confirm or deny its presence. In 1963 (Figure 5.8-7) there is no data in Lancaster Sound itself; southeastward flow is apparent off the east coast of Bylot Island (along with a hint of counterflow or eddy motion next to the coast). None of this is inconsistent with an intrusive current in eastern Lancaster Sound, but it is certainly not conclusive.

American data from 1966 (Figure 5.8-9) shows opposing westward and eastward flows on the north and south sides of Lancaster Sound respectively. Since there is only a single line of stations in the Sound itself, there is insufficient data to decide whether an intrusive flow existed or not. The pattern shown in Figure 5.8-9 is not inconsistent with such a flow, however. The 1928 Godthaab data (Figure 3-2), like the 1966 data, shows evidence of opposing flows on the north and south sides of Lancaster Sound. Again, since there is only one line of stations, delineation of any intrusive current is not possible. However, the data shown are not inconsistent with such an interpretation.

The intrusive current appears to be an essentially permanent feature of the circulation in the eastern end of Lancaster Sound. Of twelve years of data between 1928 and 1979 which were considered, eight show the existence of the intrusive current, and the other four are doubtful, usually because of sparse data. 1954 (Figure 5.8-1) is the least likely to have had the intrusive current, and it is by no means conclusive.

Given that the intrusive current is an essentially permanent feature, it will be of interest to examine some of its variations from one year to another. Consider first the extent of its westward penetration into Lancaster Sound. The eastern limit of the Sound will be taken to be a line joining Cape Sherard and Cape Hay. Table 5.8-2 gives the extent of westward penetration in each year between 1928 and 1979 for which an intrusive current was definitely present. For the years 1978 and 1979, only CTD data has been examined, so as to compare like quantities with the historical data. 1977 has not been included, as no CTD data was available from that year. The distance of penetration given in the centre column is that defined by the dynamic topography as drawn. The right-hand column gives upper and lower bounds of penetration defined by the station spacing.

Table 5.8-2

Westward Penetration of Intrusive Current

Year	Penetration (km)	Absolute Limits Based on Station Spacing
1956	23 - 76	23 - 156
1957	25 - 36	0 - 73
1960	47 - 64	44 - 121
1961	up to 46	up to 73
1962	38 - 63	36 - 71
1978	25 - 50	25 - 50
1979	25 - 72	25 - 72

The ranges of penetration for each year shown in Table 5.8-2 do not reflect the true width of the intrusive current, but rather bracket its position as well as possible, given the generally coarse station spacing (especially along the east-west axis of the Sound). In general, the intrusive current crosses the Sound between 25 to 60 km west of the entrance. The greatest recorded westward penetration is 76 km, as inferred from the interpolated dynamic heights. This exceeds anything found in the 1977 to 1979 data, with the possible exception of the September - October 1978 dynamic topography (see Figure 5.2.6-6) which extended 50 km into the Sound with no evidence of the current crossing the Sound. The minimum extent of penetration, if the 1961 data are neglected for the moment, is 23 km, i.e., approximately halfway from Cape Sherard to Cape Warrender. In 1961, stations were not occupied between Dundas Harbour and the Cape Sherard-Cape Hay line; some stations were occupied east of the line, but were not particularly useful in defining the eastern edge of the intrusive current. In 1961, therefore, the boundary of the intrusive current cannot be defined. The data surveyed here between 1956 and 1979 demonstrates that when it can be defined, the intrusive current penetrates an average of 45 km ± 19 km into the Sound. The average positions of the eastern and western edges of the cross-Sound current (as defined by the dynamic topographies in Figures 5.8-1 to 5.8-9 and 5.2.3-4 and 5.2.3-5) are, respectively 26 ± 15 km and 60 ± 16 km.

The depth of penetration figures given above include interpretation made in drawing the dynamic height contours, and therefore are somewhat subjective. Absolute limits to the penetration of the current are determined by the station positions from which the topographies are drawn. Limits to the current penetration in Lancaster Sound based upon this criterion are given in column 3 of Table 5.8-2 above. The mean penetration is 55 ± 46 km, and the mean positions of the eastern and western edges of the cross-Sound current are 22 ± 17 km and 94 ± 36 km, respectively.

Surface current speeds based on geostrophic calculations in the intrusive current (relative to the reference level of 300 dbar) are given in Table 5.8-3. This table contains only the older data collected before 1970. The speeds observed in 1978 and 1979 are discussed in detail in section 5.2.3. The values given for cross-Sound flows are likely to be significantly underestimated because of the generally wider station spacing there, in adition to the generally reduced geostrophic current speeds as compared to the actual currents.

There is considerable year-to-year variation in the computed surface speeds associated with the intrusive current. However, since none of the surveys which collected the data used to construct Table 5.8-3 were designed to measure the intrusive current, the variations in speed in Table 5.8-3 may be due to lack of suitable station spacing.

Table 5.8-3

Surface Current Speeds in the Intrusive Current

Year	North Side (cm/s)	Cross Sound (cm/s)	South Side (cm/s)
1954	—	—	—
1956	24	8	5
1957	18	23	46
1960	36	39	33(22)
1961	—	15	26
1962	93 (28)	27 (11)	19
1970	—	—	26
Mean	27 ± 8 (min) 43 ± 34 (max)	19 ± 12 (min) 22 ± 12 (max)	24 ± 13 (min) 26 ± 14 (max)

Eddy motions to the west of the intrusive current are evident in several of the dynamic topographies (Figures 5.8-1 to 5.8-8). Table 5.8-4 summarizes the apparent characteristics of the eddies found in the data considered here. Speeds shown for the eddies are based strictly on the spacing of the contour lines of geopotential anomaly; no gradient current correction has been applied.

Table 5.8-4

Eddy Characteristics

Year	Position	Sense	Approx. Diameter (km)	Approx. Velocity (cm/s)
1954	none evident	---	--	--
1956	none evident	---	--	--
1957	off Dundas Harbour	Anticyclonic	26 - 36	23
1960	off Borden Pen.	Anticyclonic	22	23 - 39
1960	off Bordeur Pen.	Cyclonic	23	22
1961	off Borden Pen.	Anticyclonic	32	18
1962	meander off Borden Pen.	Anticyclonic	28	10
1963	no data	---	--	--
1970	no data	---	--	--

In 70% of the cases studied here, there was evidence of eddy or meander-like motion west of the intrusive current. The favoured location is north of the Borden Peninsula, and the favoured sense of rotation is antycyclonic. The only cyclonic eddy evident was situated just west of an anticyclonic eddy which was located off the Borden Peninsula. The mean size of all eddies (including the scale size of the 1962 meander) is 27 ± 4 km. The mean speed (for all the eddies) is 21 ± 7 cm/sec. If only the anticyclonic eddies are considered, the mean diameter and speed are 28 ± 4 km and 20 ± 8 cm/sec respectively. The anticyclonic eddies seen off the Borden Peninsula appear to be intimately associated with the intrusive current (see Section 5.2.3 an 5.2.7 for discussion of their appearance in the 1978 and 1979 data).

In summary, although the hydrographic data in this section are not sufficiently dense in time or space to allow firm conclusions to be drawn about the year-to-year variations in the circulation of Lancaster Sound, they do allow some estimates to be made. The intrusive current appears to be an essentially permanent phenomenon, there being only one year (1954) where the data did not lend themselves to such an interpretation. Even in 1954, it is not possible to state that the intrusive current definitely did not exist. Anticyclonic eddies associated with the western edge of the intrusive current (especially on the south side) are also an important feature of the circulation in the Sound. They appear to be transient, but commonly-occurring features.

5.8.2 Baffin Island Coast

The available data from 1954 to 1970 were examined for sets of data which could be used to measure year-to-year variations in the position, strength, and path of the Baffin current south of Lancaster Sound. Six sets of suitable data were found, and are summarized in Table 5.8-5 below.

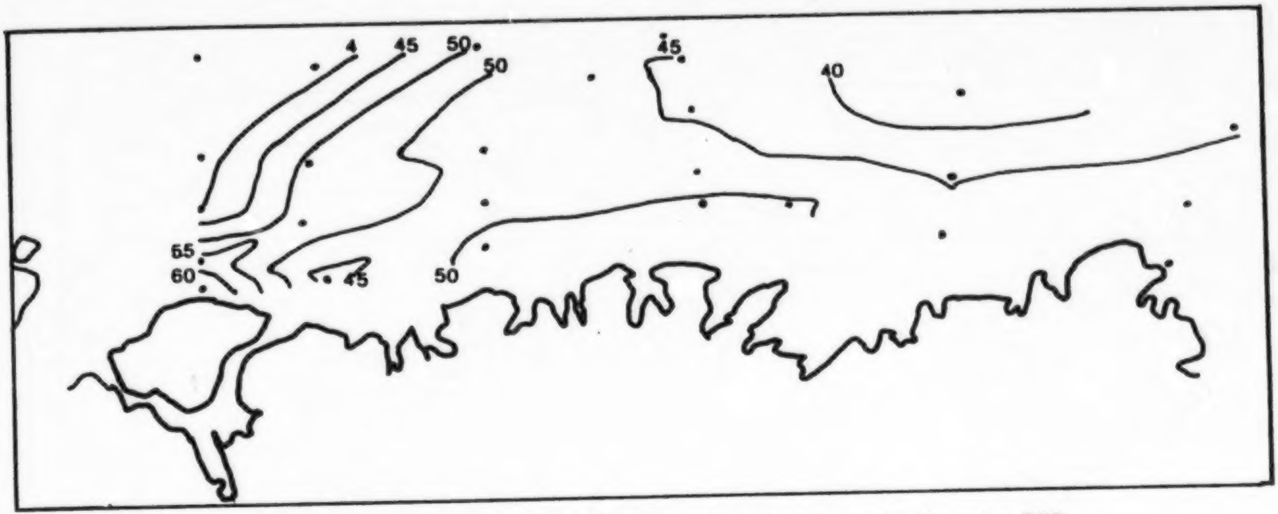

4
45
50
50
45
40
55
60
45
50

Figure 5.8-10: Dynamic topography of the surface relative to 500 dbar, September 17 - 25, 1960 in Western Baffin Bay.

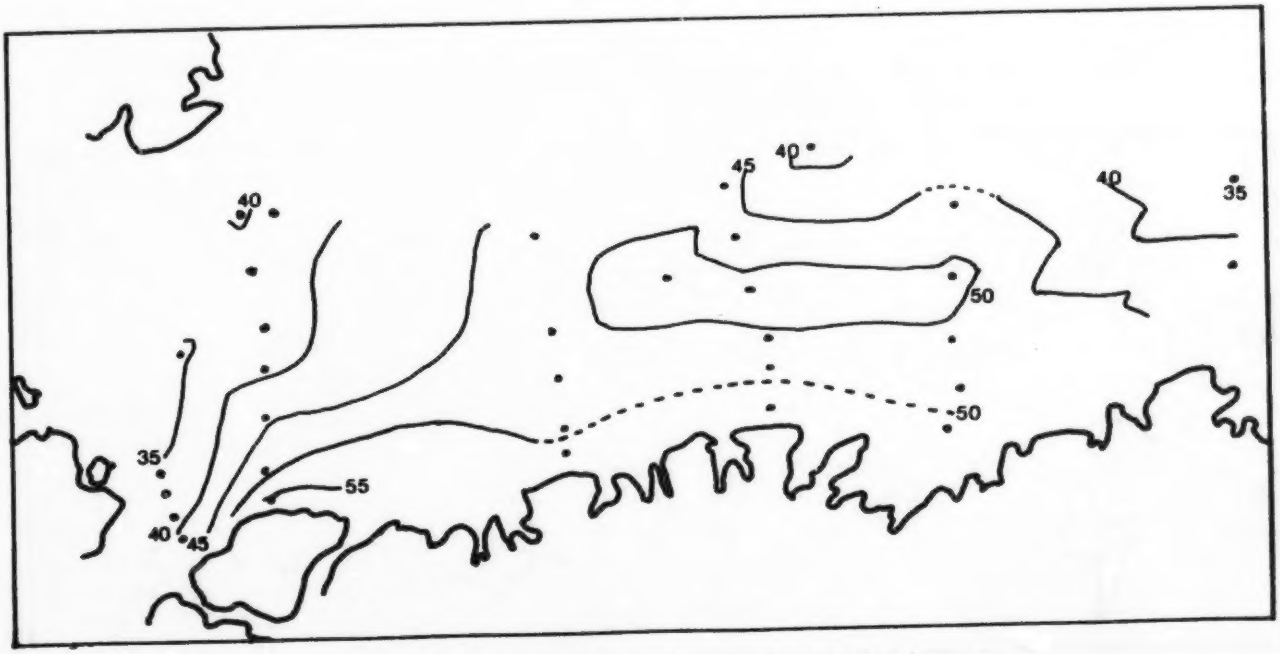

40
45
40
40
35
50
35
55
40
45
50

Figure 5.8-11: Dynamic topography of the surface relative to 500 dbar, September 15 to October 2, 1961 in Western Baffin Bay.

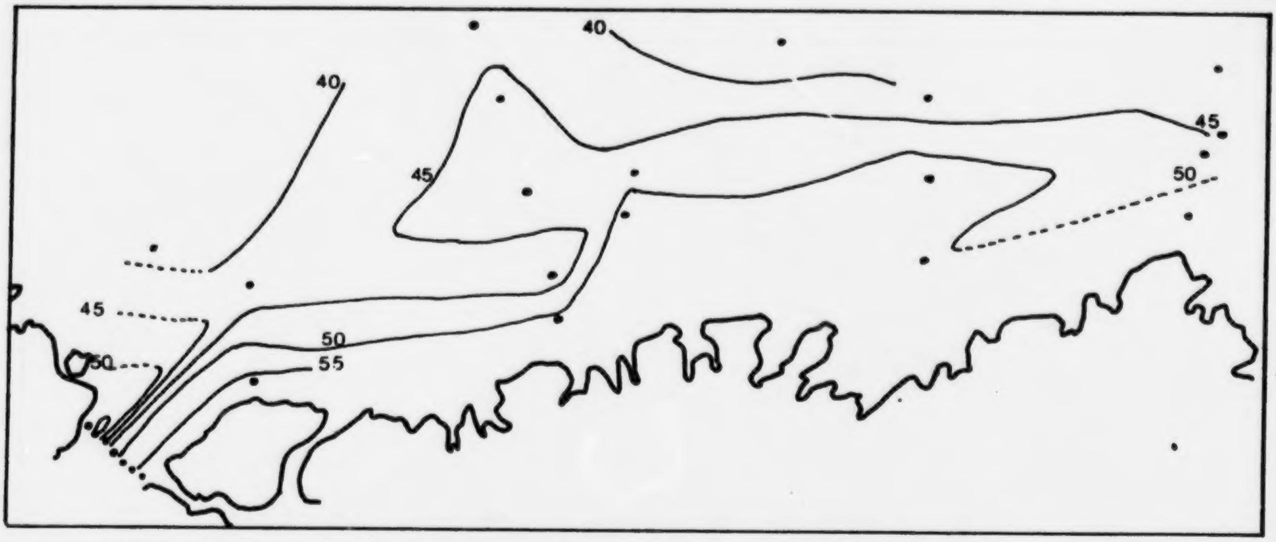

40
40
45
45
45
50
50
50
55

Figure 5.8-12: Dynamic topography of the surface relative to 500 dbar reference level, October 5-16, 1962 in Western Baffin Bay.

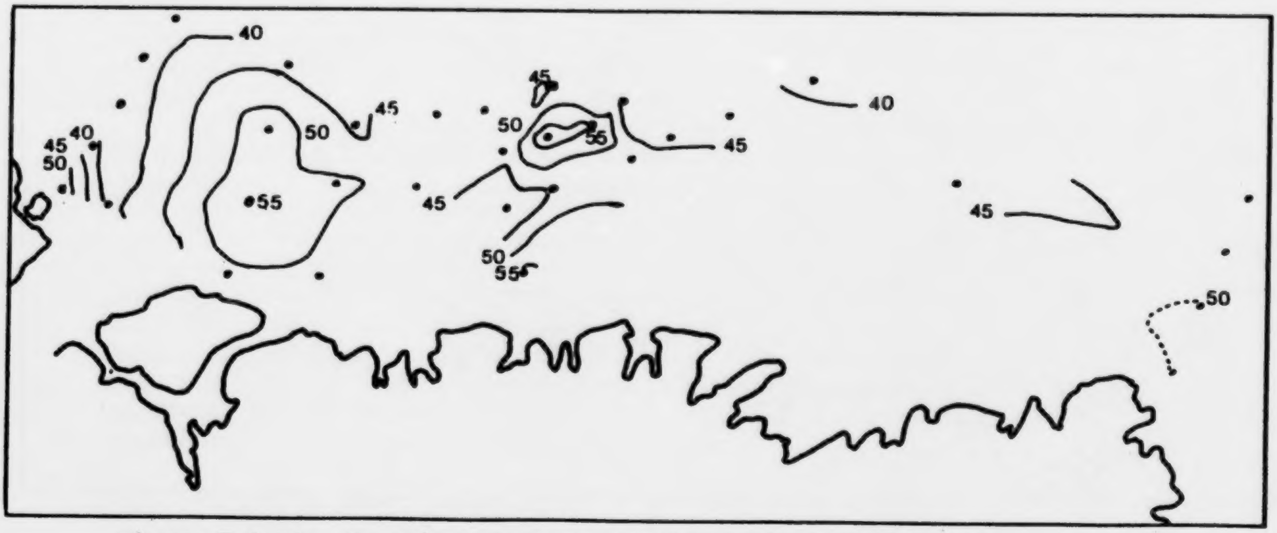

40
40
40
45
45
45
45
45
45
50
50
50
50
50
55
55
55

Figure 5.8-13: Dynamic topography of the surface relative to 500 dbar reference level, September 5 to October 8, 1964 in Western Baffin Bay.

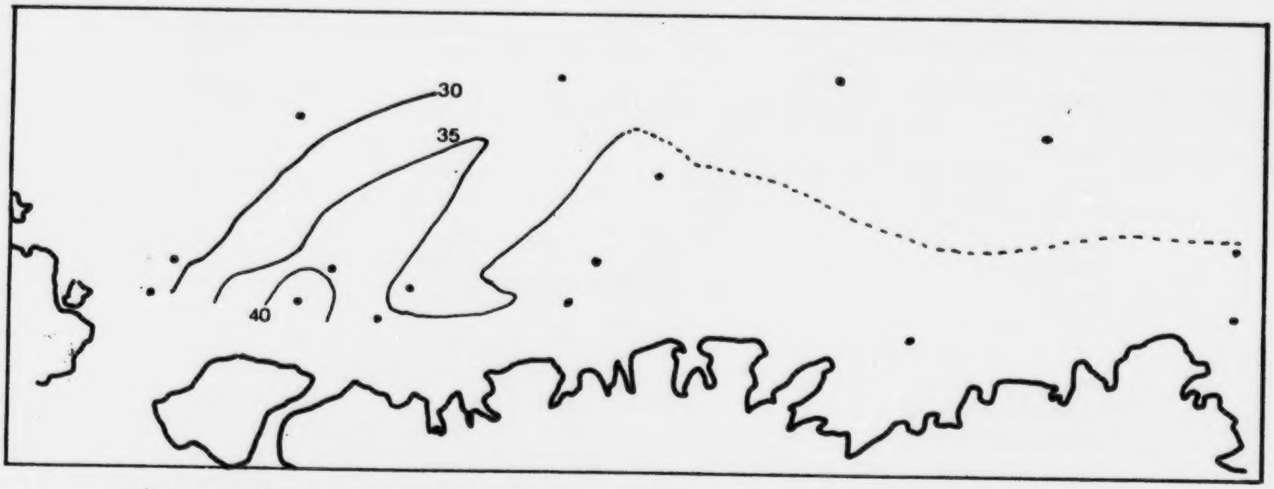


Figure 5.8-14: Dynamic topography of the surface relative to 500 dbar reference level, September 24 to October 10, 1968 in Western Baffin Bay.

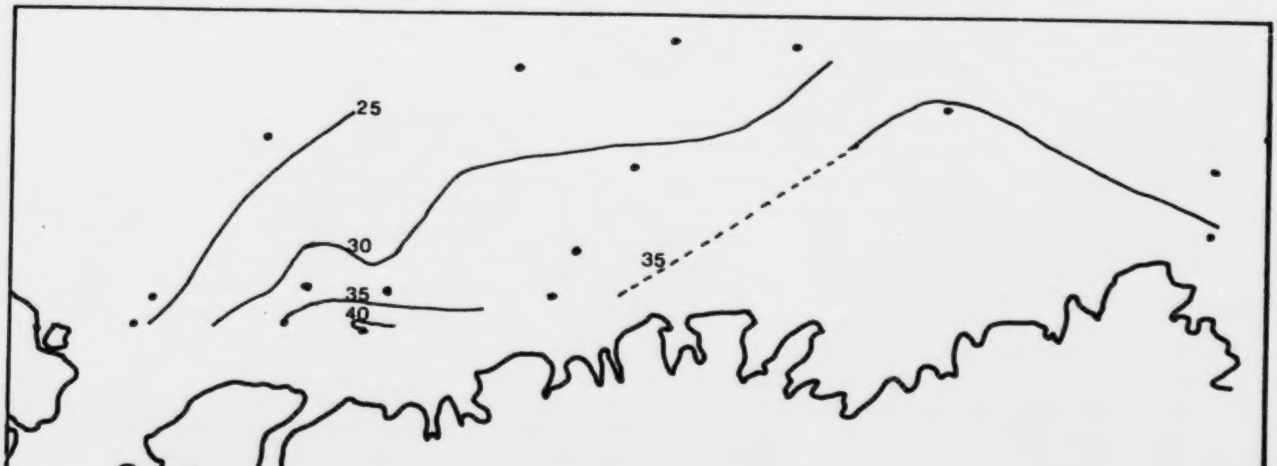


Figure 5.8-15: Dynamic topography of the surface relative to 500 dbar reference level, October 4-15, 1969 in Western Baffin Bay.

Table 5.8-5

Data Used for Year-to-Year Comparisons in the Baffin Current

Year	No. of Stations	Dates of Occupation
1960	25	Sept. 17 - Sept. 25
1961	33	Sept. 15 - Oct. 2
1962	17	Oct. 5 - Oct. 16
1964	33	Sept. 5 - Oct. 8
1968	17	Sept. 24 - Oct. 10
1969	15	Oct. 4 - Oct. 15

As was the case in Lancaster Sound, these are not the only years in which data was collected in this part of Baffin Bay, however they are the only years in which sufficient coverage was obtained to make useful comparisons with the 1978-1979 data. The data are presented in Figures 5.8-10 to 5.8-15 as dynamic topographies relative to 500 dbar, with the exception of 1968 and 1969 (Figures 5.8-14 and 5.8-15), where a 250 dbar reference level was used. The shallower reference level was necessary because measurements were not made below 250 meters in either of those years. Dotted contour lines are drawn where the interpretation of the data is doubtful.

The data from both 1978 and 1979 (examined in detail in section 5.2.6) gave clear evidence of a well defined southerly flow along the Baffin Island coast. This flow appers to have its core about 30 km offshore, roughly coinciding with the shelf break. The geostrophically calculated surface speed (relative to 300 dbar) is 8 to 12 cm/sec.

There is definite evidence of southeasterly flow along the Baffin Island coast in 1960 (Figure 5.8-10), 1962 (Figure 5.8-12) and 1969 (Figure 5.8-15). In 1961 (Figure 5.8-11), 1964 (Figure 5.8-13 and 1968 (Figure 5.8-14) the evidence is not as definite. In 1968, there is not sufficient data south of Cape Adair to define adequately the presence or absence of the current. 1964 (Figure 5.8-13) shows very little evidence of a coherent southerly flow, but there is little data close to shore. In 1961 (Figure 5.8-11) there is evidence of a weak southeasterly flow close to the Baffin Island coast. It is not well defined, however, because extrapolation of the reference level onto the shallow shelf was necessary to define that portion of the current. A much broader southeasterly flow is apparent between 100 and 150 km offshore south of Clyde River. This current is separated from the flow on the shelf by a large anti-cyclonic eddy.

Of 8 years of data considered (including 1978 and 1979) 5 show clear evidence of a continuous southeasterly flow along the Baffin Island coast. Of the remaining three cases, two are ambiguous while the third shows a large-scale distortion in the flow. The Baffin Current may be thought of as a permanent feature, but one that is subject to some large-scale perturbations.

Both the 1978 and 1979 dynamic topography charts (Figures 5.2.6-5 & 6) show that the Baffin Current follows the edge of the Baffin Island shelf quite closely (see Section 5.2.6). The 1960 to 1969 data is not sufficiently detailed over the slope region to demonstrate whether or not this is usually the case.

The 1978 and 1979 data indicate that considerable variation can occur over the course of a summer and over the length of the Baffin Island coast in the geostrophically-derived speeds of the Baffin Current. This renders year-to-year comparisons of the current strength difficult, since generally only one set of measurements were made in a given year. Station spacings were generally too coarse to detect the relatively narrow current core along the edge of the shelf, and thus the resulting surface current speed estimates will tend to be low. Table 5.8-6 shows typical and maximum surface current speeds for each year for which there is data.

Table 5.8-6

Surface Speeds in the Baffin Current

(Based on Geostrophic Calculations)

Year	Reference Level (dbar)	Typical Speed (cm/s)	Maximum Speed (cm/s)
1960	500	4	8
1961	500	4	7
1962	500	4	5
1964	500	—	—
1968	300	3	--
1969	250	5	8
1978	300	12-26	35
1979	300	10-20	29

The 1940 "Northland" cruise found core speeds of 20 cm/sec (relative to 1500 dbar) in the Baffin Current. The 1960-1969 speeds are much lower than both the 1978 and 1979 values, and the 1940 value, despite the differences in reference levels. It seems most likely that this difference arose from the much coarser station grids found in the 1960-1969 data. The 1940 and 1978-1979 speeds are in much better agreement, probably because of the relatively close station spacing used.

As has been noted in Section 5.2.5, the area off the mouth of Pond Inlet seems to be a transition zone between the Baffin Current proper (as it exists along the east Baffin Island coast) and the eddy zone east of Bylot Island. Consequently, flow in this area (between Cape Jameson and Cape Graham Moore) may be in any direction. Southeasterly flows would indicate that the Baffin Current had reformed at that point, while flows in other directions would indicate that the current was reforming further down the coast. Table 5.8-7 lists the direction of flow in this zone by year.

Table 5.8-7

Direction of Flow Between Cape Graham Moore and Cape Jameson

Year	Direction
1960	SW
1961	SE
1962	SE
1964	W
1968	SW - SE
1969	NE - SE
July 26 - August 16, 1978	NE - SE
September 10 - 12, 1978	SE
October 2 - 3, 1978	SE
August 7 - 9, 1979	SW
August 26 - 29, 1979	W - SE
October 4 - 5, 1979	SE

The 1978-1979 results show that the changes in this region take place at intervals shorther than one month, and therefore that differences from one year to another are reflections of this fact. The data in Table 5.8-7 do, however, represent 12 separate samplings of the current, and therefore may be used to estimate that the frequency of occurrences of the Baffin Current being organized north of Cape Jameson is 75%. The frequency with which it forms as far north as Pond Inlet is 42%.

5.9 Water Masses

5.9.1 Introduction

The basic description of the water masses of Baffin Bay and Lancaster Sound in Section 3 remains valid when the 1978 and 1979 CTD data are taken into account. There are some changes in the details of the structure of the water column which have come to light and which are worthy of description. The two areas in which Muench's (1971) description requires some modification are the upper 50 metres of the water column, and the interface between, the Arctic Water layer and the Atlantic Water layer. The stratification of the water in these zones is more complex than has been described by Muench, and requires some further elaboration.

5.9.2 Upper Zone

During the summer season, the upper portion of the Arctic Water (depths ≤75 metres) becomes modified by surface processes, such as solar heating, wind mixing and ice melt. The result of these modification processes is the production of a highly variable surface layer overlying the uniformly cold bulk of the Arctic Water. An example of such an upper layer may be seen in the temperature and salinity cross-sections for line 13 on August 25, 1979 (Figures 5.9-1 and 5.9-2) extending offshore from eastern Bylot Island. The depth of the modified layer in this example is between 25 and 50 metres, with the exception of the area within 40 km of the Bylot Island shoreline, where the influence of colder, fresher water flowing out of Lancaster Sound may be seen. Within this upper zone, temperatures may range from -1°C to 3.0°C or greter, and salinities from 28.0 °/oo to 32.5 °/oo. (Surface salinities may be as low as 20.0 °/oo in Navy Board Inlet and Eclipse Sound). Such low salinities are not evident in the example shown, because it was taken in an area where little ice-melt or run-off was occurring.

The structure of the upper zone is of interest from both the physical and biological points of view. The development and decay of wind-mixed layers and near-surface pycnoclines have great importance for both fields. The development of drift currents, the depth of penetration of inertial oscillations and theinfluence of wind drift currents on the drogued drifters all may be affected by the structure of the upper layer. Sharp pycnoclines and subsurface temperature extrema may be important for plankton populations.

The structure of the upper zone exhibits a great deal of variability, being subject to wind mixing, solar heating, ice melt and the construction and erosion of pycnoclines. Bailey (1957) observed a 4 to 5°C cooling of the upper 10 metres of Prince of Wales Strait five days after previously open water became ice-choked. Because of the prevailing low water temperatures, solar heating does not have a great influence on density. Density stratification is chiefly due to salinity variations.

Examples of the type of upper-layer structure observed in 1979 are shown in Figure 5.9-3(a-d). The examples show profiles typical of various stages in the growth and decay of wind-mixed layers and near-surface pycnoclines. Figure 5.9-3(b) shows a well-developed mixed layer almost 25 m thick. The station is 130 km east of Philpots Island and was occupied the day after the end of the severe storm of August 18-19. No restratification of the mixed layer was yet apparent. Figure 5.9-3(d) shows an example of an old mixed layer overlain by a newly-developed layer. The station is located 110 km east of the Baffin Island coast. Figures 5.9-3(a) and (c) show profiles taken near (within 15 km) the east of Devon and Baffin Islands, respectively. Both illustrate an essentially

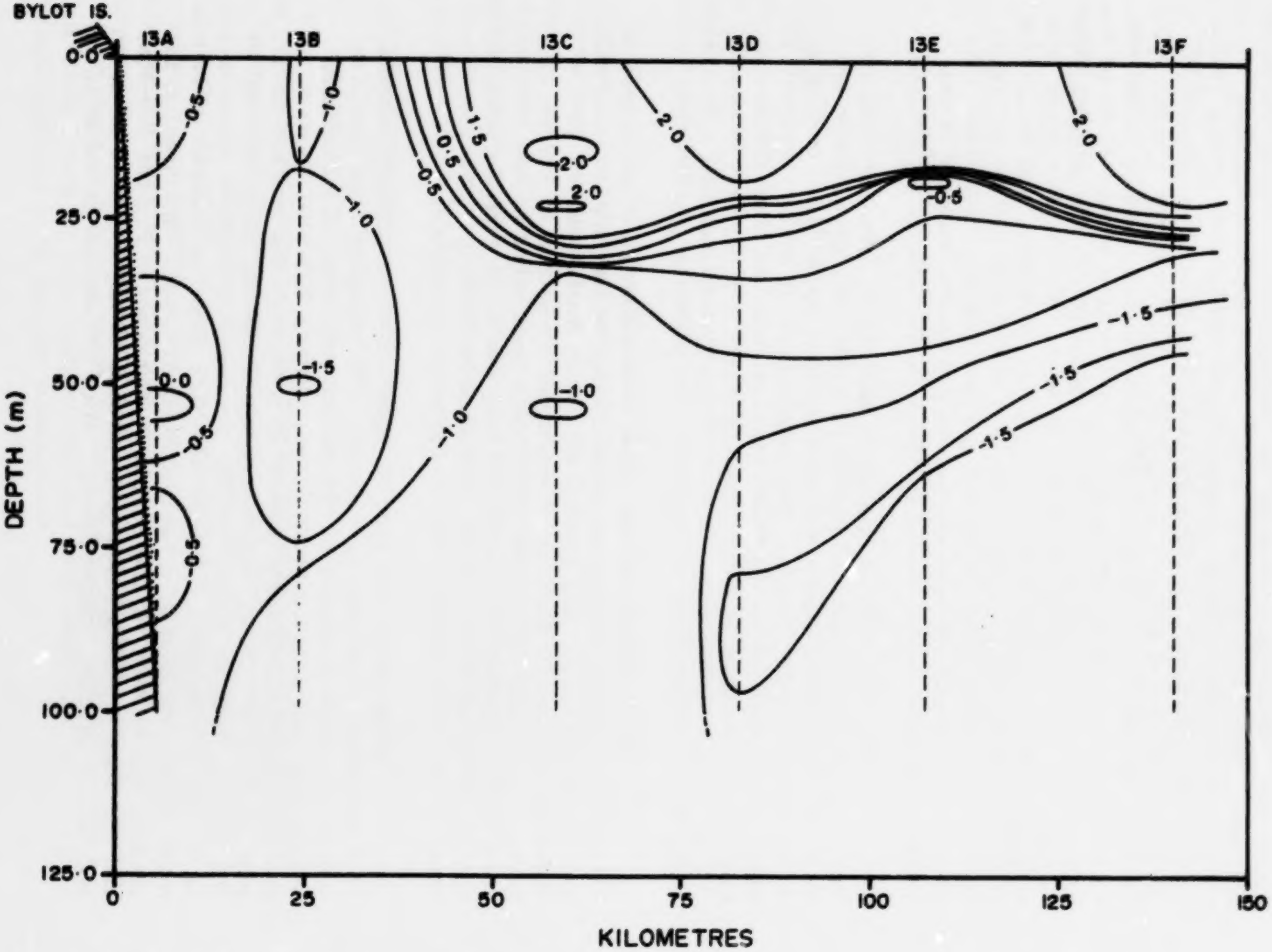


Figure 5.9-1: Line 13, August 25-26, 1979. Temperature cross-section, upper 100 metres.

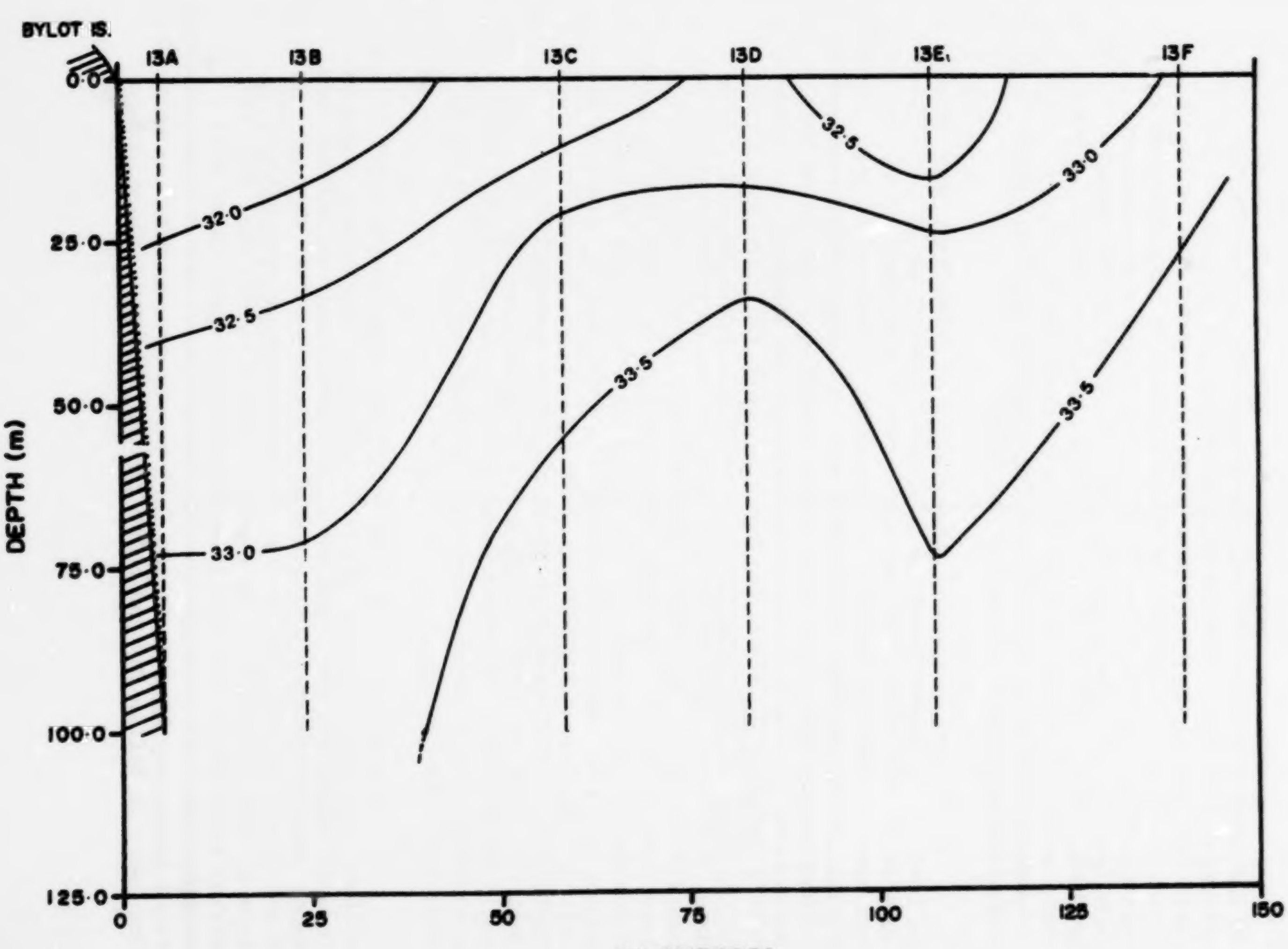


Figure 5.9-2: Line 13, August 25-26, 1979. Salinity cross-section, upper 100 metres.

continuous pycnocline extending to the surface. The coastal stations are more subject to restratification through the addition of fresh water from runoff or ice-melt. This is evident in the lower surface salinities and the lack of a sharply-defined upper layer near the coast in Figures 5.9-1, 5.9-2 and Figures 5.9-3(a) and (c).

In offshore zones, where the upper layer is not as subject to the advective processes associated with the strong coastal currents, the upper layer usually preserves its well-mixed character, and appears to become deeper throughout the season (see Figure 5.9-4 for example which shows successive occupations of a station 30 km east of Devon Island). The temperature gradients developed in the upper zone have little effect on the density gradient. Since there is no significant salinity change in the upper zone, the heated surface water becomes rapidly mixed throughout the upper layer, resulting in quite uniformly warm temperatures through its entire thickness.

The production and preservation of subsurface warm layers is less likely under the above conditions than it is at a station such as 3A (see Figure 5.9-3a) where the warmer, more saline layer has been overlain by fresher, colder water flowing south from Jones Sound. As may be seen in Figure 5.9-4c, the upper layer in these offshore zones can become very thick, reaching 80 metres by late September. Figure 5.9-5 is a histogram of the depth of all mixed layers observed in 1979. The depth of the mixed layer was defined as the depth at which the first pycnocline was encountered. If a density gradient extended to the surface, the mixed-layer depth was recorded as zero. The depths recorded were, with a few exceptions, less than 40 metres. The mean depth was 13.5 ± 12 m. Figure 5.9-6 shows a plot of the depth of the mixed layer with time for the summer of 1979. The key identifies the locations (by area) of the various stations. The lack (at this time) of wind records applicable to the oceanic areas in the study zone precludes a detailed study of layer development. However, one may note, the rapid deepening of the mixed layer in Baffin Bay on August 19-20, coinciding with a severe storm, and its absence in the sheltered waters of Jones Sound.

Figure 5.9-7 is a scatter plot of mixed-layer depth versus surface salinity, for the 1979 data. Note the triangular shape of the plot envelope, which suggests that low surface salinities (and hence usually stronger subsurface stratification (cf. Figures 5.9-3(b) and (c)) do not favour the production of deep mixed layers. The diagram will be somewhat biased by the fact that the mixing involved in the formation of a uniform upper layer will increase the surface salinity. The inhibition of the development of mixed layers may be seen in the differences between stations near the coast in Baffin Bay and those further offshore. (Stations in

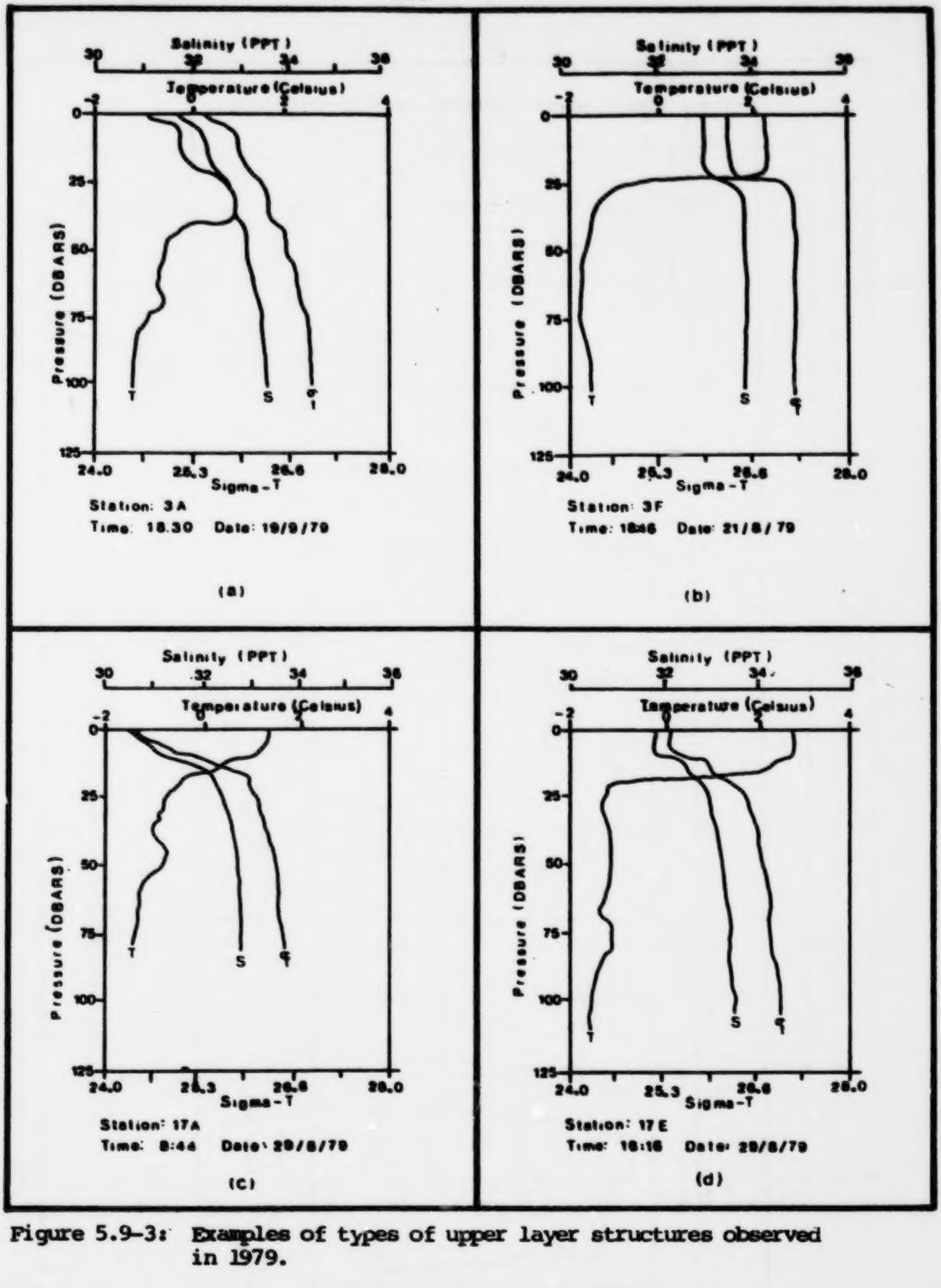


Figure 5.9-3: Examples of types of upper layer structures observed in 1979.

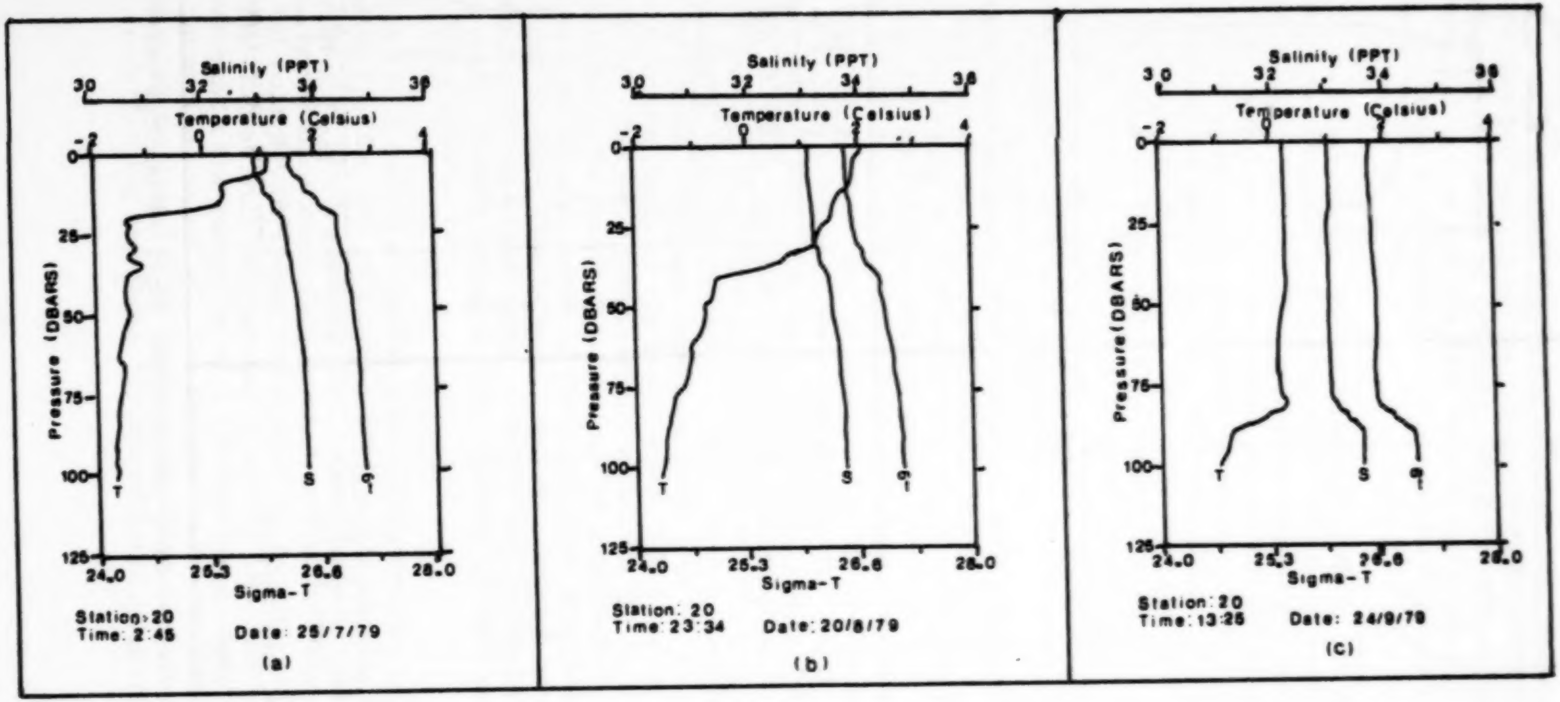


Figure 5.9.4: Successive temperature, salinity and σ_t profiles at offshore station 20, in 1979.

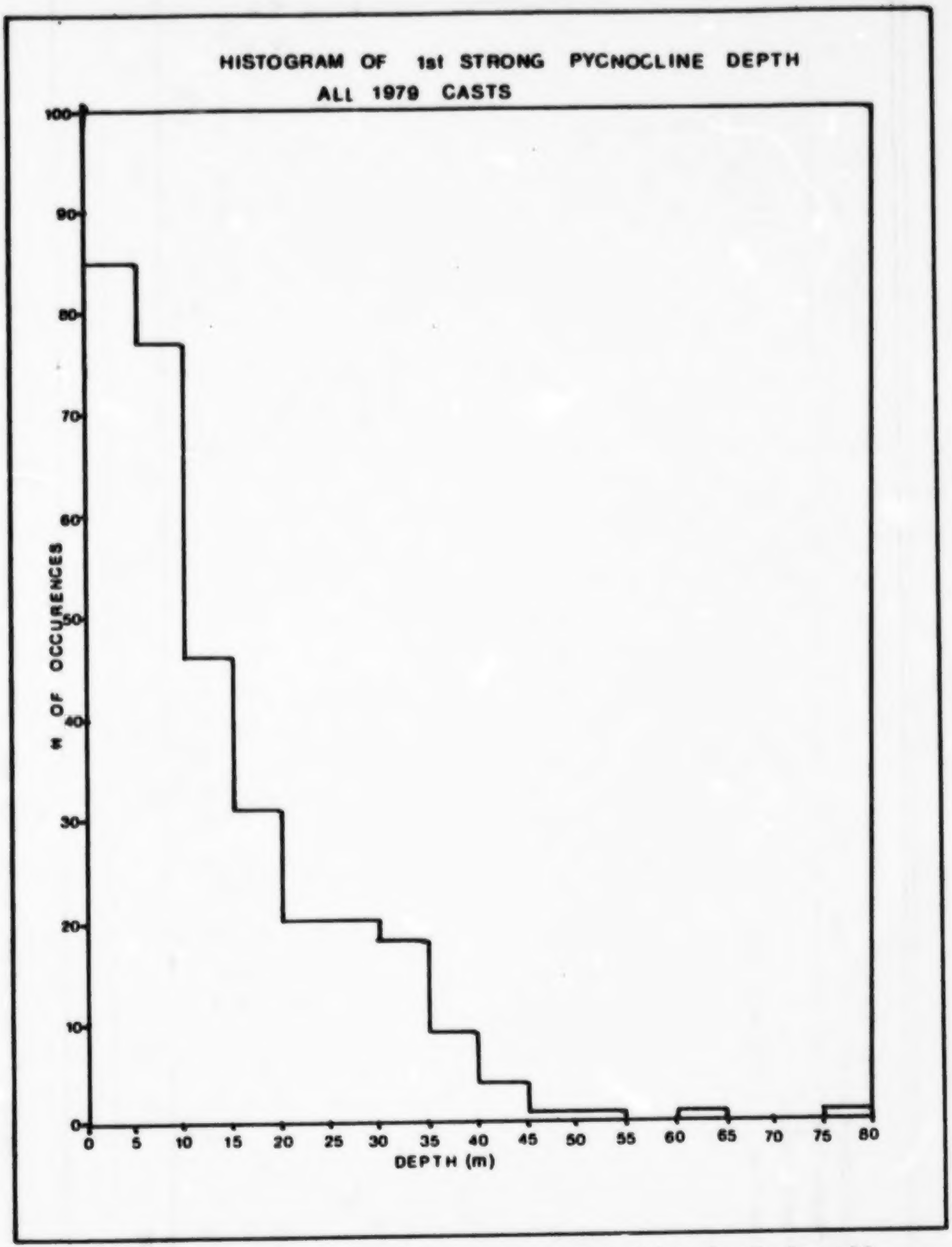


Figure 5.9-5: Histogram of first strong pycnocline depth for all 1979 casts.

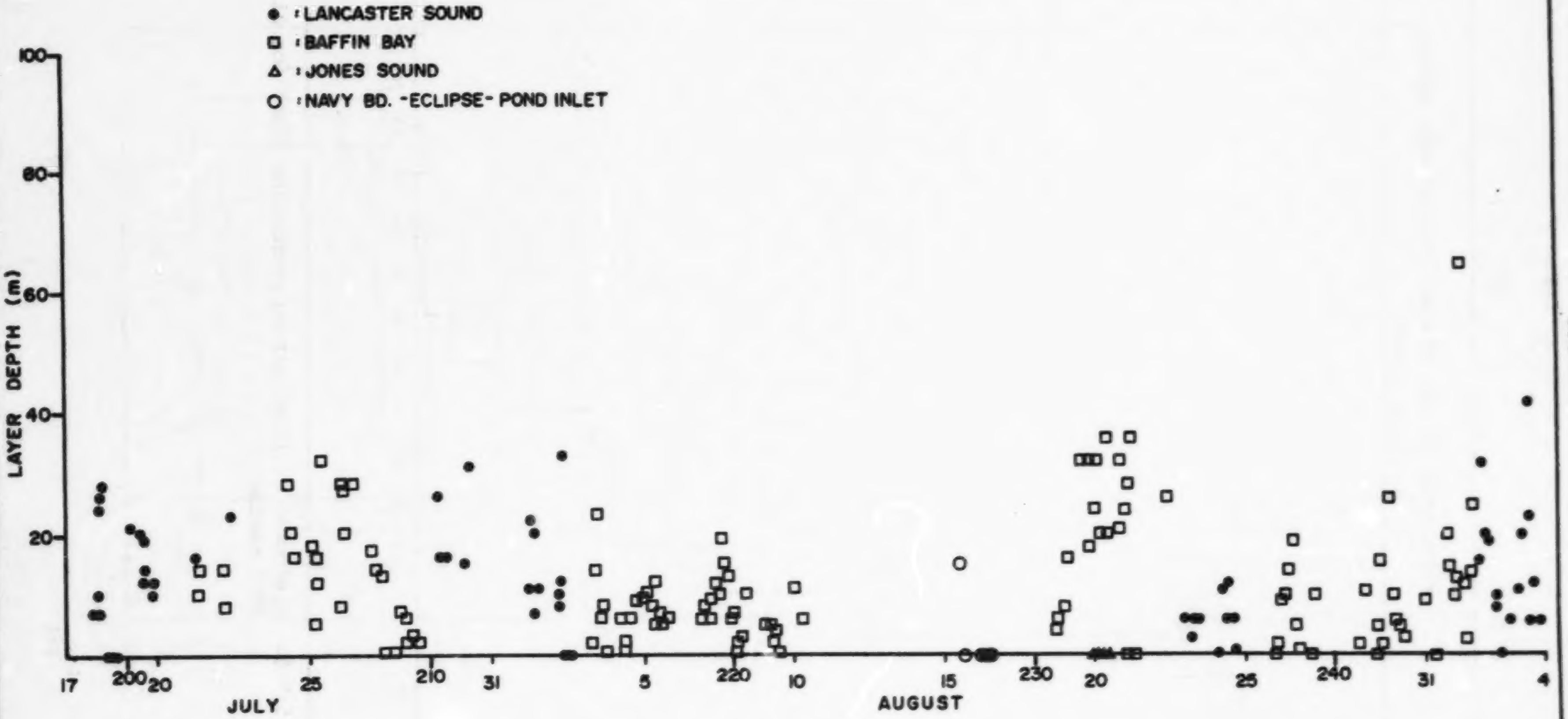


Figure 5.9-6(a): Depth of the mixed layer for all 1979 CTD stations plotted as a function of observation time, July 17 to September 4, 1979.

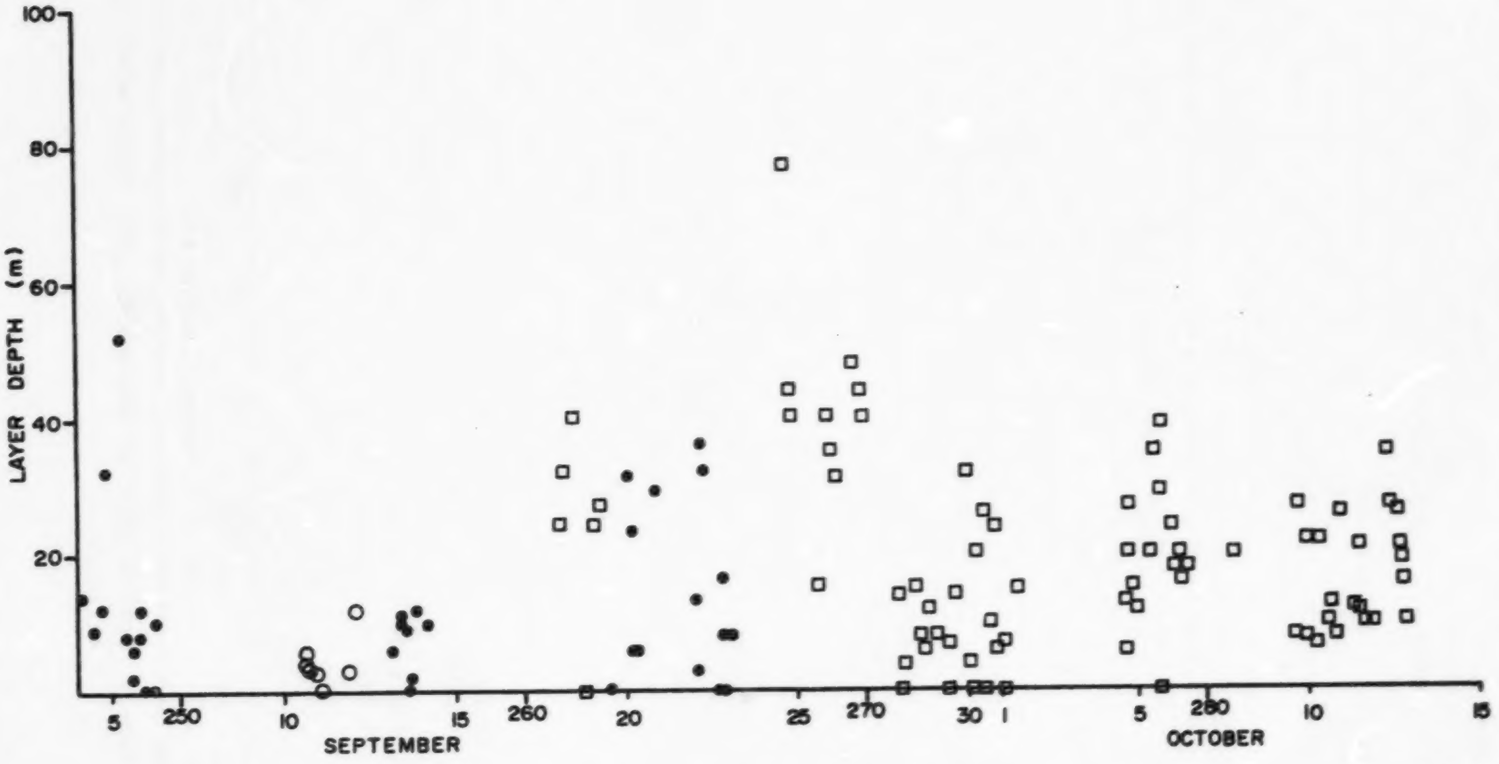


Figure 5.9-6(b): Depth of the mixed layer for all 1979 CTD stations plotted as a function of observation time, from September 5 to October 15, 1979.

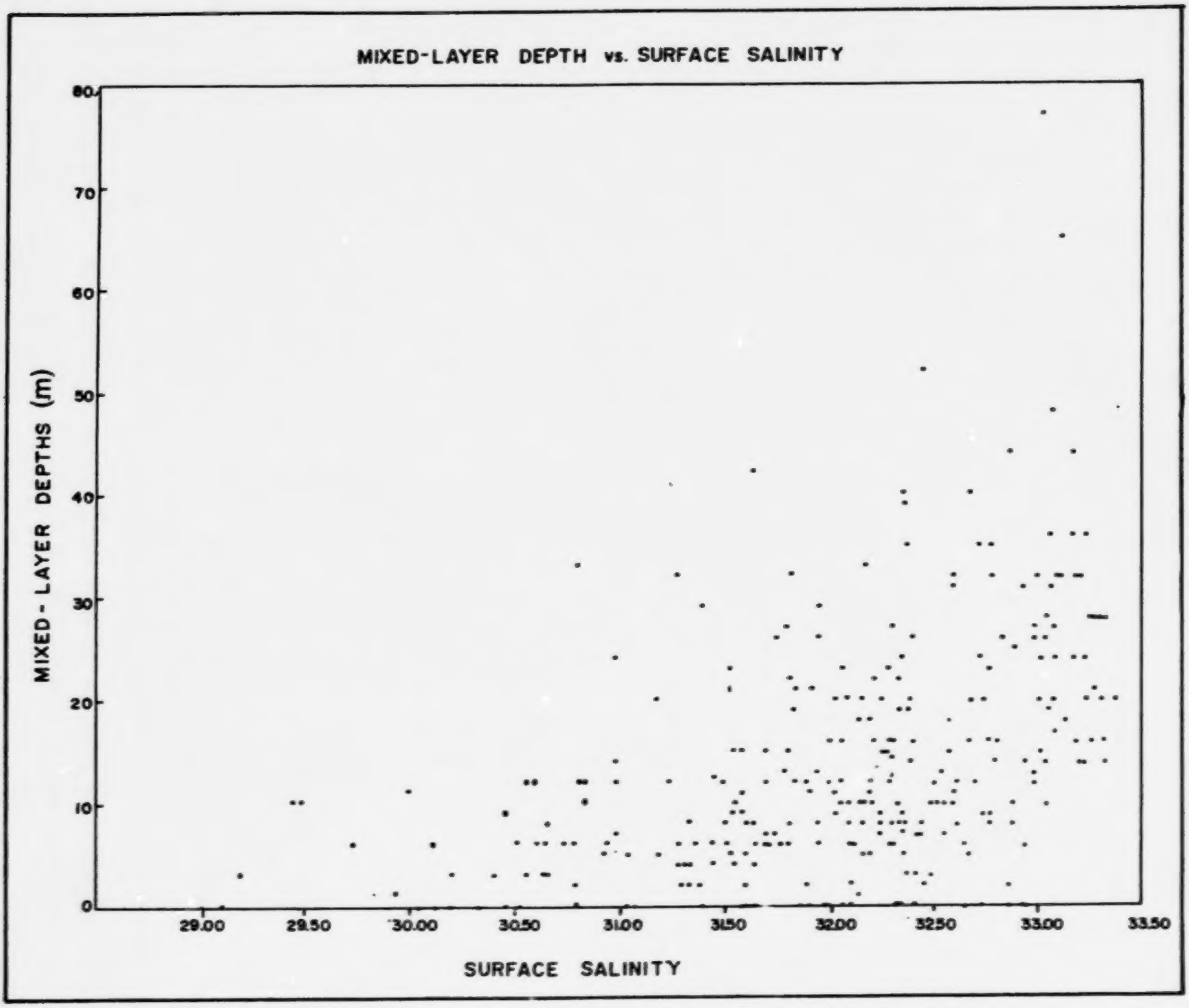


Figure 5.9-7: Scatter plot of the mixed layer depth versus surface salinity.

Lancaster Sound were not considered). The average depth of the uniform layer was computed for all stations occupied in 1979 at the nearshore end of lines extending into Baffin Bay and for the corresponding stations at the other end of the line. The mean mixed-layer depth for the inshore stations was 8 ± 9 m; the mean depth for the offshore stations was 17 ± 9 m. The difference could be caused by a difference in the wind fields close to and far away from the coast. Wind data which could resolve this question is not presently available. It may also be due to the difference in stratification between nearshore and offshore areas. Areas near shore are freshened near the surface by the cold, low-salinity water associated with the Baffin Current and also by runoff (see Figures 5.9-1 and 5.9-2). The development of mixed layers may be inhibited by this advection of cold fresh water in the coastal flows.

In summary, the upper zone of the Arctic Water layer is a zone of high variability, usually less than 40 metres in depth. Although wide variations in temperature in the surface layer are observed, they have little effect on the density stratification, which is primarily controlled by salinity. Consequently, away from coastal areas, and in the absence of melting ice or currents which may advect water of different salinity, the density stratification in the upper layer is not readily altered after the layer has been mixed.

5.9.3 The Arctic Water - Atlantic Water Interface

The transition zone between the cold Arctic Water mass and the warmer, more saline Atlantic Water mass is the site of a great deal of interleaving structure in the water temperature. Figure 5.9.8 is an example of this sort of temperature structure. Between 250 and 500 m depth, numerous temperature fingers are visible. Their thickness ranges from 6 to 30 meteres, and the temperature differences are up to 0.5°C. A change in temperature of this magnitude can be seen in as little as 5 metres depth change. The $_t$ profile through the same region is smooth, with the exception of some small-scale noise, which was probably caused by the inability of the conductivity circuit in the CTD to respond quickly enough to the rapid temperature changes above and below the layers. The interleaving is present at very reduced amplitude in the salinity trace, some portions of which are steplike in nature.

The distribution of the temperature interleavings does not show any discernable spatial pattern, beyond a general tendency to follow the distribution of Atlantic water. Stations exist, however, where the Atlantic water is present, but no significant evidence of interleaving is found. Figure 5.9-9 shows such an example. The shaded areas in Figure 5.9-10 show the areas where interleaving was noticeable for each of the four 1979 station occupations.

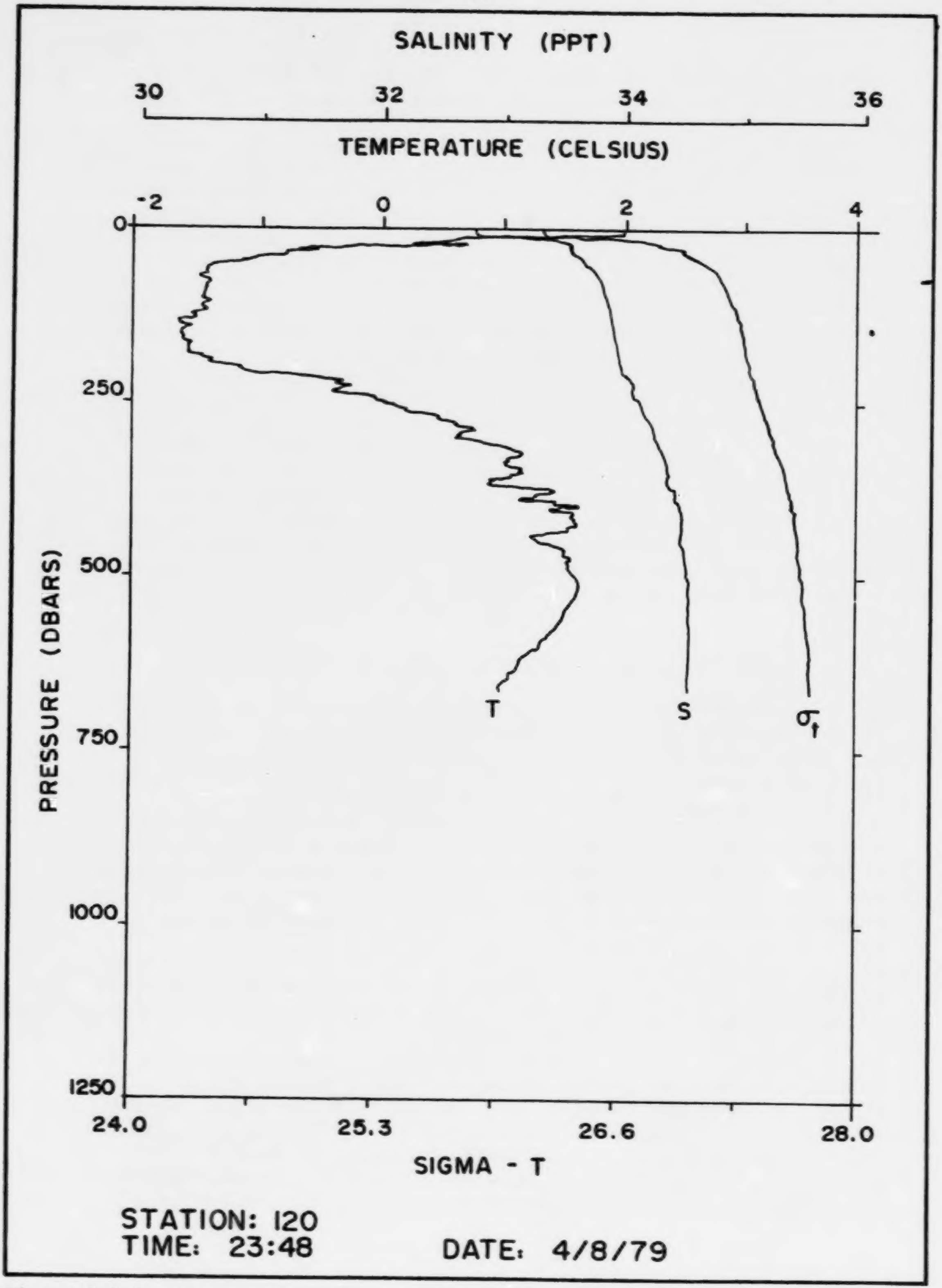


Figure 5.9.8: An example of temperature interleaving in the Arctic-Atlantic interface.

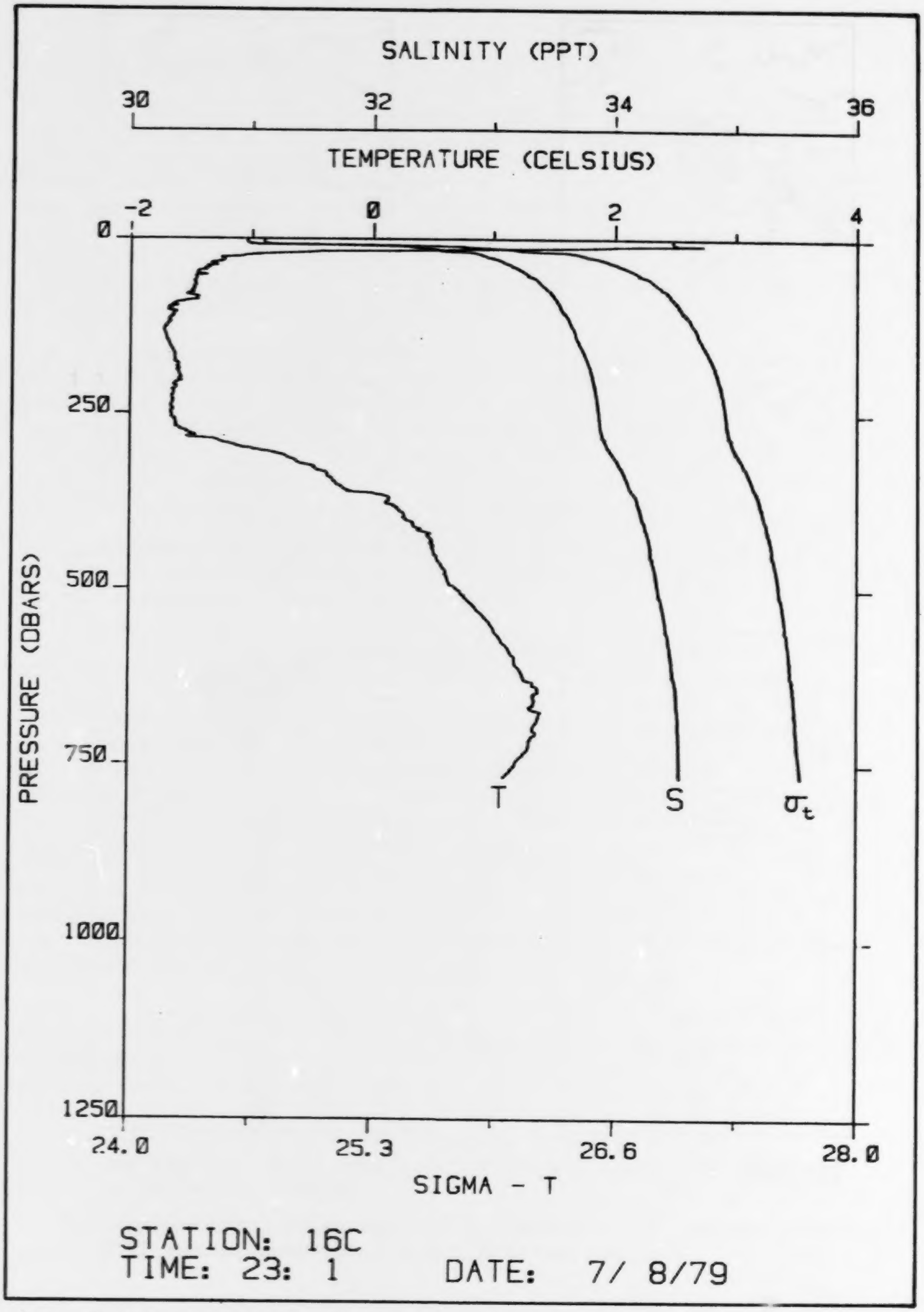
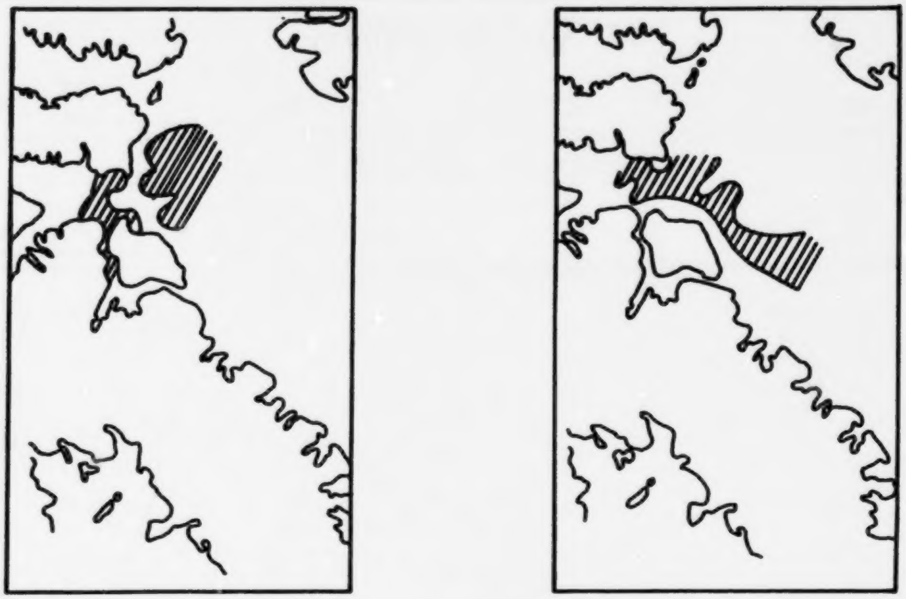
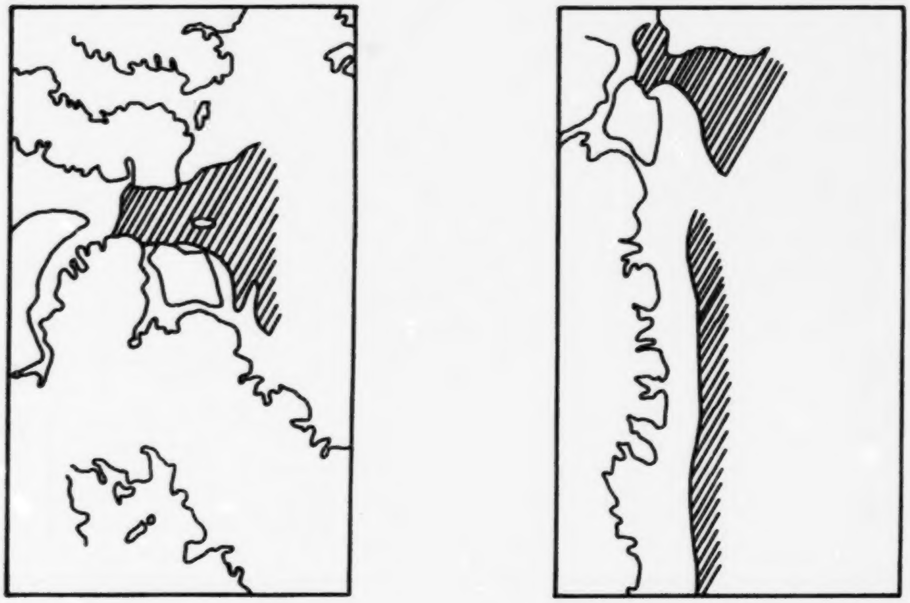


Figure 5.9-9: An example of a station with no interleaving of temperatures in the Arctic-Atlantic water interface.



(a) July 17-28, 1979

(b) July 29- Aug. 10, 1979



(c) Aug. 15- Sept. 6, 1979

(d) Sept. 7- Oct 17, 1979

Figure 5.9-10: The distribution of temperature interleaving in the Arctic-Atlantic interfaces, summer 1979.

6. DISCUSSION

The circulation of western Baffin Bay is dominated by the southward flowing Baffin Current, as has been documented in many previous studies (e.g. Killerich, 1939; Dunbar, 1951; Collin and Dunbar, 1964). In the present study, the circulation features have been measured with much greater spatial and temporal resolution than ever before. The results show that often intense and relatively narrow currents constitute much of the total flow of the Baffin Current. These strong currents can significantly vary with time both as to location and spatial pattern.

The most striking example of such a circulation feature is the intrusion of the Baffin Current into the mouth of Lancaster Sound. The current takes the form of a relatively narrow, swift-flowing coastal currente along the east coasts of Devon, Bylot, and Baffin Islands. It typically penetrates some 60 km to the west along the south coast of Devon Island before turning south, crossing the Sound and flowing out to the east along the coast of Bylot Island. A strong current system such as this plays a major role in the transport of pollutants, sea-ice and icebergs, and would have significant effects upon any exploratory drilling operations in Lancaster Sound or northwest Baffin Bay.

The bulk of this report has consisted of a detailed description of the low frequency surface circulation as it was observed in 1978 and 1979. The stability and persistence of the circulation is obviously of vital importance in assessing the environment risks associated with exploratory drilling in this area, in view of the strenght of the ocean currents encountered. A complete understanding of the fundamental dynamics of the current system would be required to truly assess significant temporal and spatial variations of intense circulation features such as the intrusive current. The current state of physical oceanography is not equal to such a task. It is possible, however, to point out some features of the current system which offer important clues to its dynamical nature, and to list some of the processes which might be responsible for them.

Muench (1971) suggested that the cyclonic circulation of northern Baffin Bay is driven by a combination of wind stress and near-surface lower salinity wedges found near the coast due to ice melt and land runoff. Also contributing to the latter driving mechanism is the lower salinity (and hence density) of the water flowing out of Smith, Jones and Lancaster Sounds; the lower salinities close to shore result in the required baroclinic pressure field for the Baffin Current.

The net southward flow through the Sounds connecting Baffin Bay to Arctic Ocean are explained as being due to differences in internal mass distribution (Muench, 1971) based on comparisons of the internal mass distribution relative to 250 dbar (approximately 250 m), assuming that the 250 dbar surface is level. Unfortunately the assumption cannot be tested without a levelling survey through the Arctic Islands. Muench (1971) suggested that variations in the outflow can result from atmospheric pressure gradients along the direction of the flow, citing comparisons of the movements of ice island WH-5 in Nares Strait with pressure differences between Alert, N.W.T. and Thule, Greenland.

The results of the present study allow for some investigation of the relative importance of the two suggested driving mechanisms; wind stress and low salinity wedges. Since the analysis of the meteorological data collected during the 1978 and 1979 field studies is not yet available, correlations between the wind stress over Baffin Bay and the observed circulation have not been attempted. However, the availability of the winter 1978-1979 current measurements are worth consideration; contrary to results found in Crosier Strait (Greisman and Lake, 1978), the winter speeds in the Baffin Current are lower than those observed in the summer. The decrease is most pronounced at 35 meters and is considerably reduced at 250 m. In short, the flow becomes more nearly barotropic in winter, suggesting that the baroclinic component is chiefly a summer phenomenon. The decrease of the baroclinic component of the flow occurs coincidentally with the destruction of the stratification of the water column by convective mixing under the growing ice. Since the winter wind stress curl over Baffin Bay is 4 times that prevailing in the summer (Muench, 1971), the winter weakening of the baroclinic part of the Baffin Current suggests that either the Baffin Bay wind stress is relatively unimportant in driving the circulation or that the stress transfer through the pack ice is very low.

The fact that the decline of the baroclinic flow coincides with the erosion of the stratification of the upper part of the water column suggests that the nearshore wedges of lower salinity water may indeed be important in driving the Baffin Current system. However, the volume and horizontal extent of these low salinity structures is not known. Pending this information, a full assessment of the importance of this drivifng mechanism cannot be made.

In view of the net outflow of water from the Arctic Ocean to Baffin Bay, it may seem surprising that the Baffin Current should turn west at Cape Sherard and flow into Lancaster Sound, apparently counter to the prevailing outflow. LeBlond (1980) has shown that many of the channels in the Archipelago (including Lancaster Sound) are wide enough to accommodate opposing, geostrophically-balanced flows on opposite shores. He also showed that a geostrophic current flowing with a coast on its right-hand side is capable of following the coast around corners, provided that the radius of curvature of the coast is sufficiently large that the Rossby number (Ro=u/fr, where u is the current velocity and f is the Coriolis parameter) is much smaller than 1. The Rossby number for the Baffin Current where it rounds Cape Sherard ranges between 0.1 and 0.2, suggesting that the current is indeed capable of turning that corner, since inertial accelerations will be relatively unimportant.

Muench (1971) attributed the turning of the Baffin Current at Cape Sherard to conservation of potential vorticity and the sudden deepening of the water south of Cape Sherard. The sign of the curvature depends, however, upon the magnitude of the horizontal shear in the current, which is difficult to determine due to the limited width of the current. It is possible that topographic control through conservation of potential vorticity may contribute to the turning of the current at Cape Sherard.

The fact that Lancaster Sound is wide enough to accommodate two opposite geostrophically-balanced flows and that the Baffin Current should be capable of turning the corner at Cape Sherard does not explain the second striking feature of the circulation in Lancaster Sound, which is the relatively abrupt southward turn the current executes offshore of Cape Warrender (about 60 km into the Sound) and the subsequent cross-channel flow. The cross-channel flow is of comparable width and speed to the coastal flows themselves. It is not a broad, cross-channel drift, but is a well defined current. Although apparently quite localized, it is subject to significant perturbations, and in particular has at least two distinct flow patterns.

A zone of large horizontal density gradients appears across the intrusive current. This is evident in the cross-channel flow as a front separating the relatively cold, fresh surface waters of Lancaster Sound from the warmer, more saline surface waters in the eastern end of the Sound. A similar structure has been observed in the Gulf of St. Lawrence (Tang, 1980) where the fresh, outflowing waters of the St. Lawrence River encounters the more saline Gulf waters. Tang explains the formation of the intense cross-channel current.....(as) "a result of the byoyancy influx from the estuary". The cross-channel current turns east forming a strong coastal flow (the Gaspé current) along the south shore of the Gulf.

There are differences between the circulation in the Gulf of St. Lawrence as described by Tang and the circulation in Lancaster Sound. The flow in Lancaster Sound to the west of the front does not always appear to be eastward. There is eastward flow; however, it is not steady over the whole channel, and appears, from the limited measurements available, to be quite irregular.

Nevertheless, it is tempting to speculate that the conjunction of the inflowing Baffin Current with the colder, fresher surface waters of western Lancaster Sound is at least partially responsible for producing the cross-Sound current. The front, and the associated baroclinic flow necessary to balance the pressure gredient may be the result of a balance between the intruding flow and the apparent outflow from Lancaster Sound. Further tests of this driving mechanism require improved estimates of the flow in western Lancaster Sound.

The intrusive flow and the currents immediately downstream fluctuate significantly in a variety of ways. The cross-Sound flow appears to have at least two modes and occasionally penetrates to the Borden Peninsula, where a large (50 km) transient anticyclonic gyre is produced. Fluctuations in speed over periods from a few days to several tens of days are observed at fixed locations in the intrusive current. Anticyclonic eddies with scale sizes of 20-25 km and periods of 30 to 60 hours were observed along the east coast of Bylot Island.

Baroclinic instability has been suggested as a possible mechanism for producing fluctuations in strong Arctic flows. A two-layer model (Mysak and Schott, 1977) was fitted to the parameters observed for the Baffin Current in the eastern part of Lancaster Sound in order to test whether the current was likely to be subject to baroclinic instability. No unstable solutions were found for the Baffin Current off Philpots Island. At Cape Sherard, the maximally unstable solution has a period of 3.2 days and a wavelength of 100 km. At Cape Hay, for the observed ranges of stratification and shear parameters, maximally unstable solutions were found with wavelengths from 30 to 60 km and periods from 1.5 to 2.0 days. On the basis of these very limited tests, it seems that baroclinic instability is important only in the portion of the Baffin Current which flows along the north coast of Bylot Island. Fluctuations which could be produced by the mechanism are apparently limited to scales of less than 50 km in space or 2 days in time. Thus, while it appears likely that baroclinic instability may be capable of producing perturbations like the anticyclonic eddies observed along the east coast of Bylot Island, it is not likely to produce the longer period fluctuations observed in current meter records at Cape Hay. It is encouraging to note, however, that the eddies are observed downstream from the Cape Hay area and not near Philpots Island or Cape Sherard where the model indicates that unstable perturbations are not likely to develop.

Speculations such as those above indicate how further analysis of the data set could be used to evaluate hypotheses about the dynamics of the northern Baffin Bay region. The coherent set of drifter, water mass and direct current measurements, obtained in the 1978 - 1979 studies, in addition to providing the overall surface circulation description needed to assess the environmental risks associated with exploratory drilling, is invaluable for future investigations of the dynamics of such a complex current system. Further analysis of the data with that in mind should be fruitful. In addition, a coherent data set such as this provides an excellent basis on which to plan further field studies which may be desired to confirm or deny hypotheses about the physical processes underlying the observed phenomena.

7. References

Avis, R.A. and L.K. Coachman, 1971: Current Measurements in Smith Sound - Northern Baffin Bay. North Water Project Scientific Report No. 2. Arctic Institute of North America, Washington, D.C.

Bailey, W.B., 1957: Oceanographic Features of the Canadian Archipelago. J. Fish, Res. Board, Canada, 14, 731-769.

Barber, F.G., 1978: A note on the oceanography of Eclipse Sound. Unpublished manuscript, Marine Sciences Directorate, Ottawa.

Barber, F.G., 1979: Lancaster Sound - some 1960 Data. Unpublished manuscript, Marine Sciences Directorate, Ottawa. 177 p.

Barber, F.G. and A. Huyer, 1971: On the water of the Canadian Arctic Archipelago - an atlas presentation of 1961 and 1962 data. Unpublished manuscript. Canada Dept. Energy, Mines and Resources, Marine Sciences Branch, Ottawa. 5 p.

Barber, F.G. and A. Huyer, 1977: On the oceanography of Jones Sound, N.W.T. Marine Sciences Branch Manuscript Report Series No. 40, Ottawa, 48 p.

Barnes, C.A. 1971: Oceanographic investigations in Baffin Bay in 1940. United States Coast Guard Bulletin, 30, 27-56.

Bessis, J.L., 1979: Operational data collection and platform location by satellite. Conference on Data Collection and Location by Satellite, Service ARGOS, Toulhouse, France.

Birch, J.R., 1980a: Data Report 5 - 1979 Nearshore Studies of the Physical Oceanography of Cape Warrender, Cape Fanshawe and Cape Hay. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Birch, J.R., 1980b: Data Report 6 - Analysis of Water Level Record for Johnson Bay, N.W.T. Aug. 22, 1978 - May 12, 1979. Unpublished manuscript. Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Coachman, L.K. and K. Aagaard, 1974: Physical Oceanography of Arctic and Sub-Arctic Seas Marine Geology and Oceanography of the Arctic Seas. Springer-Verlag, New York, N.Y.

Coates, J.L., 1975: The NIMBUS F Random Access Measurement System (RAMS). IEEE Trans. on Geoscience Electronics, GE-13, J, p. 18.

Collin, A.E., 1958: An oceanographic study of Prince Regent Inlet, the Gulf of Boothia and adjacent waters. Manuscript Report Series (Oceanographic and limnological) No. 13, Fisheries Research Board of Canada, pp. 66.

Collin, A.E., 1962: On the oceanography of Lancaster Sound. Unpublished Ph.D. Thesis, McGill University, Montreal.

Collin, A.E., and M.J. Dunbar, 1964: Physical Oceanography in Arctic Canada. Oceanogr. Mar. Biol. Ann. Rev. 2, 45-75.

Day, C.G., 1968: Current measurements in Smith Sound, Summer of 1963. U.S.C.G., Oceanographic Report 16. 75-84.

Dunbar, M.J., 1951: Eastern Arctic Waters, Fisheries Research Board of Canada, Bulletin No. 88, Ottawa, 131 p.

Dunbar, M.J., M. Dunbar and D.C. Nutt, 1967: The Baffin Bay North Water project, Report No. 1. Research Paper No. 45. Arctic Institute of North America, Montreal. 71 p.

Fissel, D.B., 1980: Data Report No. 2: Subsurface Current Measurements in Western Baffin Bay and Lancaster Sound, 1978-1979. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Fissel, D.B. and J.R. Birch, 1980: Data Report No. 4: Current Profile Measurements in western Baffin Bay and Lancaster Sound, Summers 1978 and 1979. Unpublished manuscript. Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Fissel, D.B. and J.R. Marko, 1978: A Surface Current Study of Eastern Parry Channel, N.W.T., Summer 1977. Arctic Sciences Ltd. Contractor Report Series 78-4, Institute of Ocean Sciences, Sidney, B.C. 66 p.

Fissel, D.B. and G.R. Wilton, 1978: Surface Current Measurements in Eastern Lancaster Sound, N.W.T. - Summer 1977. Arctic Sciences Ltd. Contractor Report Series 78-3, Institute of Ocean Sciences, Sidney, B.C., 72 p.

Fissel, D.B. and G.R. Wilton, 1980: Data Report No. 1: Subsurface Current Measurements in western Baffin Bay and Lancaster Sound, 1978-1979. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Foreman, M.G.G., 1977: Manual for Tidal Heights Analysis and Prediction. Unpublished Manuscript. Pacific Marine Science Report 77-10, Institute of Ocean Sciences, Sidney, B.C. 97 p.

Foreman, M.G.G., 1978: Manual for Tidal Currents Analysis and Prediction. Unpublished manuscript. Pacific Marine Science Report 78-6, Institute of Ocean Sciences, Sidney, B.C. 70 p.

Fournier, R.O., J. Marra, R. Bohrer and M. Van Det, 1977: Plankton Dynamics and Nutrient Enrichment. J. Fish Res. Board Canada, 34, 1004-1018.

Franceschetti, A.P., D.A. McGill, N. Corwin and E. Uchupi, 1964: Oceanographic observations in Kennedy Channel, Kane Basin, Smith Sound and Baffin Bay. United States Coast Guard Oceanographic Report No. 5. Washington, D.C. 98 p.

Greisman, P. and R.A. Lake, 1978: Current Observations in the Channels of the Canadian Arctic Archipelago adjacent to Bathurst Island. Unpublished manuscript. Pacific Marine Science Report 78-23, Institute of Ocean Sciences, Sidney, B.C. 127 p.

Godin, G., 1966: The Tides in the Labrador Sea, Davis Strait, and Baffin Bay. Manuscript Report Series No. 2. Marine Sciences Directorate, Ottawa.

Godin, G., 1977: The Analysis of Tides. University of Toronto Press, 264 p.

Hendershott, M.C., 1964: Inertial oscillations of tidal period Ph.D. Thesis. Harvard University. 135 p.

Herlinveaux, R.H., 1970: Icepack 8/68 - Oceanographic and biological observations. Fisheries Research Board of Canada Technical Report No. 159. Ottawa. 60 p.

Herlinveaux, R.H., 1974: Surface movements in Canadian Arctic Waters with some accompanying temperature and salinity observations. Unpublished manuscript. Pacific Marine Science Report. Institute of Ocean Sciences, Sidney, B.C. 36 p.

Horne, E.P.W., 1978: Interleaving at the subsurface front in the Slope Water off Nova Scotia. J. Geophys. Res., 83, 3659-3671.

Hunkins, K., 1967: Inertial Oscillations of Fletcher's Ice Island (T-3). J. Geophys. Res., 72, 1165-1174.

Killerich, A.B., 1939: A theoretical treatment of hydrographical observational material, Godthaab expedition. Meddelelser on Groenland 78, 1 - 148.

Le Bond, P.H., 1980: On the surface circulation in some channels of the Canadian Archipelago. Arctic 33, 189-197.

Lemon, D.D., 1980: Data Report No. 3: CTD Data from Western Baffin Bay and Lancaster Sound, 1978 and 1979. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Marko, J.R., 1978: A Satellite-based study of Sea Ice Dynamics in the Central Canadian Arctic Archipelago, Contractor Report Series 77-4. Institute of Ocean Sciences, Sidney, B.C.

Marko, J.R., 1981: The Ice Environment of Eastern Lancaster Sound - Northwest Baffin Bay. Arctic Sciences Ltd. prepared for Petro-Canada.

Maxwell, J.B., P.J. Duck, R.B. Thomson and G.G. Vickers, 1980: The Climate of Northwestern Baffin Bay. Unpublished manuscript, Canadian Climate Centre Report No. 80-2, Atmospheric Environment Service, Downsview, Ontario. 105 p.

Mecking, L. (1906), Die Eistrift aus dem Bereich der Baffin Bai beherrscht von Strom und Wetter. Veroffentlichungen des inst. fur Meereskunde und des Geogr. Inst. Univ. Berlin 7, 1-135.

Monin, A.S., V.M. Kamenkovich and V.G. Kort, 1977: Variability of the Ocean. J.J. Lumley, editor of the English translation. Wiley-Interscience, New York. 241 p.

Moynihan, M.J. and R.D. Muench, 1971: Oceanographic observations in Kane Basis and Baffin Bay, May and August - October, 1969. United States Coast Guard Oceanographic Report No. 44. CG 373-44. Washington, D.C. 143 p.

Muench, R.D., 1971a: The Physical Oceanography of the Northern Baffin Bay Region. Baffin Bay-North Water Project Scientific Report No. 1. Arctic Institute of North America, Washington, D.C. 150 p.

Muench, R.D., 1971b: Oceanographic conditions in Smith Sound and northern Baffin Bay, September 1968. United States Coast Guard Oceanographic Report No. 37. Washington, D.C. p. 1-20.

Muench, R.D., 1972: Oceanographic conditions in the Northern Baffing Bay Region, 24 July - 6 August, 1970. United States Coast Guard Oceanographic Report No. 54, CG 373-54. Washington, D.C.

Munk, W. and N. Phillips, 1968: Coherence and band structure of inertial motion in the sea. Rev. Geophys, 6, 447-472.

Mysak, L.A. and F. Schott, 1977: Evidence for a baroclinic instability of the Norwegian Current. J. Geophys. Res., 82, 2087-2095.

NORDCO Ltd., 1979: A Study of Iceberg Drift in Lancaster Sound, July - October, 1978. Submitted to Petro-Canada. NORDCO Ltd., St. John's Newfoundland.

Palfrey, K.M. and C.G. Day, 1968: Oceanography of Baffin Bay and Nares Strait in the summer of 1966 and current measurements in Smith Sound, summer 1963. United States Coast Guard Oceanographic Report No. 16 (CG 373-16). Washington, D.C. 204 p.

Pollard, R.J., 1980: Properties of near-surface inertial oscillations. J. Phys. Oceangr., 10, 385-398.

Pollar, R.J. P.B. Rhines and R.O.R.Y. Thompson, 1973: The deepening of the wind-mixed layer. Geophys. Fluid Dyn., 3, 381-404.

Ramster, J.W., D.B. Hughes and G.K. Jurnes, 1978: A steadiness factor for estimating the variability of residual drift in current meter records. Dt. Hydrogr. Z., 31, 230-236.

Riis-Carstensen, E., 1936: The Godthoab Expedition 1928: the hydrographic work and material. Meddelsev om Gronland, 78. 101 p.

Saelen, O.H., 1963: Studies in the Norwegian Atlantic current. Geofys. Publikasjoner Norske Videnskops - Akad. Oslo., 23, 1 - 82.

Sekarak, A.D., R.A. Buchanan, M.G. Foy, H. Bain, G.L. Walder and H.E. Stallard, 1979: L.G.L. Limited submitted to Petro- Canada. Toronto, Ontario. 412 p.

Singleton, R.C., 1969: An algorithm for computing the mixed radix fast Fourier transforms. IEEE Transactions on Audio and Electro-acoustics, 17, 93-103.

Smith, E.H., 1931: Arcitc ice, with special reference to its distribution to the North Atlantic Ocean; the Marion expedition to Davis Strait and Baffin Bay, 1928. United States Coast Guard Bulletin 19 (3). p. 1-221.

Smith, E.H., F.M. Soule and O. Mosby, 1937: The Marion Expeditions to Davis Strait and Baffin Bay: Part II, Physical Oceanography. United States Coast Guard Bulletin, 19.

Tang, C.L., 1980: Mixing and Circulation in the Northwestern Gulf of St. Lawrence: A Study of a buoyancy-driven current system. J. Geophys. Res., 85, 2787-2796.

Walker, E.R., 1977: Aspects of Oceanography in the Archipelago. Unpublished manuscript. I.O.S. Note - 3. Institute of Ocean Sciences, Sidney, B.C. 186 p.

Webster, F., 1968: Observations of inertial period motions in the deep sea. Rev. Geophys. 6, 473-490.

Wunsch, C., 1975: Internal tides in the ocean. Rev. Geopys. and Space Phys., 13, 167-182.

APPENDIX

A listing of data reports prepared as part of this study which (1) describe methods and instrumentation used in data collection and (2) summarize the data in the form of plots and listings:

Fissel, D.B. and G.R. Wilton 1980: Data Report No. 1: Subsurface Current Measurements in Western Baffin Bay and Lancaster Sound, 1978-1979. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Fissel, D.B., 1980: Data Report No. 2: Satellite-Tracked Drifting Bouy Movements in Baffin Bay and Lancaster Sound, Summer 1978 and 1979. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Lemon, D.D., 1980: Data Report No. 3: CTD Data from Western Baffin Bay and Lancaster Sound, 1979 and 1979. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Fissel, D.B. and J.R. Birch, 1980: Data Report No. 4: Current Profile Measurements in western Baffin Bay and Lancaster Sound, Summers 1978 and 1979. Unpublished manuscript. Arctic Sciences Ltd., Sidney, B.C. (Revied 1981)

Birch, J.R. 1980a: Data Report 5 - 1979 Nearshore Studies of the Physical Oceanography of Cape Warrender, Cape Fanshawe and Cape Hay. Unpublished manuscript, Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)

Birch, J.R. 1980b: Data Report 6 - Analysis of Water Level Record for Johnson Bay, N.W.T. Aug. 22, 1978 - May 12, 1979. Unpublished manuscript. Arctic Sciences Ltd., Sidney, B.C. (Revised 1981)